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UNDERWAY VIBRATION SURVEY ON THE USS OKINAWA (LPH-3) – A CASE STUDY OF SUPERSTRUCTURE VIBRATION

by

Donald C. Robinson

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ACOUSTICS AND VIBRATION LABORATORY
RESEARCH AND DEVELOPMENT REPORT

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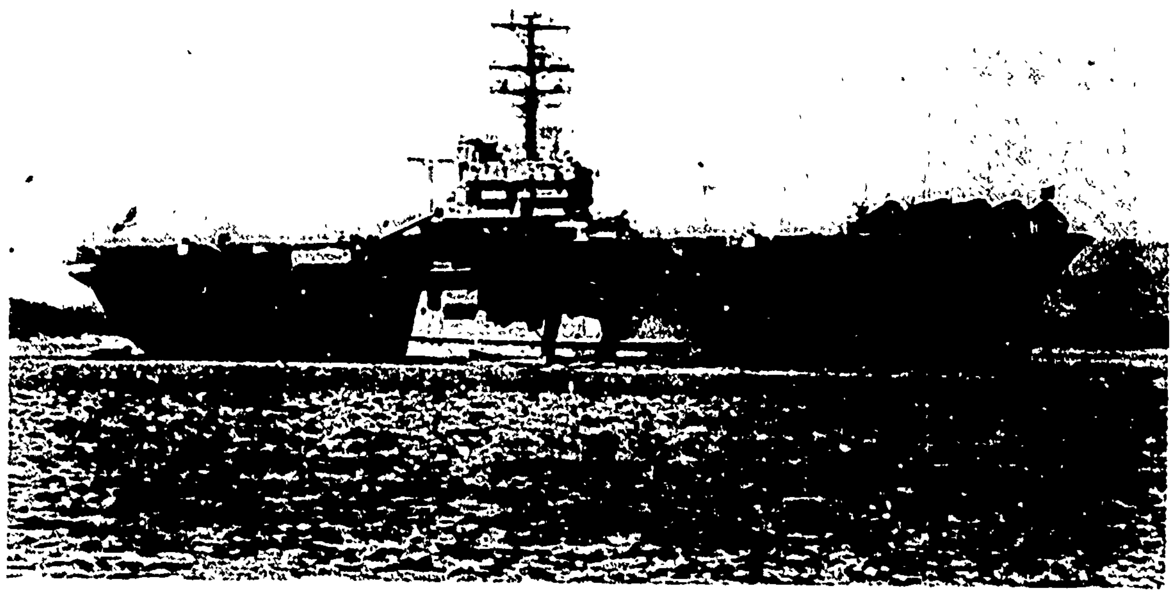


USS OKINAWA (LPH-3)

ABSTRACT

An underway vibration survey was performed on USS OKINAWA (LPH-3) to establish critical frequencies and determine maximum vibratory levels of the hull, island, radar mast, main propulsion machinery, and Mark 63 Director 2. Free route (straight course) steady-speed runs were made in addition to hard turns, crashback maneuvers, and anchor drop tests. Large magnifications of athwartship vibration motion of the island-radar mast structure relative to the hull were noted for speeds above 85 rpm. The superstructure of OKINAWA influences the island and radar mast vibrations whose levels are important for the successful operation of electronic equipment mounted on these structures. Because of the characteristics of the superstructure, the ratio of the higher flexural hull frequencies to the fundamental frequency differs from that found on a number of other class vessels.

ADMINISTRATIVE INFORMATION

This assignment was authorized by Bureau of Ships letters Serial 436-189 of 20 July 1962 and Serial 436-247 of 8 October 1962. Funds were provided under Project SCN 30013.

Preliminary results of the vibration survey conducted on OKINAWA including measurements of the hull, island, and a gun director mounted on the island were forwarded to the Bureau of Ships as enclosure (1) to David Taylor Model Basin letter Serial 7-156 of 17 May 1963 (Technical Note SML-760-54). More detailed analysis of the island vibration was reported in David Taylor Model Basin letter Serial 7-221 of 15 July 1963. Vibration levels of the mast and fantail were given in References 1 and 2,* respectively.

INTRODUCTION

The USS OKINAWA (LPH-3) is an amphibious assault carrier, similar to a Mariner Class of ship, constructed from new plans. During 25 March through 29 March 1963, an underway vibration survey of OKINAWA was made by the Model Basin at the request of the Bureau of Ships because the vibration levels measured by Philadelphia Naval Shipyard during builder's trials in May 1962 were considered excessive, particularly on the island structure. Prior to the vibration survey, several minor structural changes were made on the ship, e.g., a gun director pedestal on the island was lowered and its base relocated aft for support by existing stachions. In addition, the flexible coupling connecting the main condenser intake pipe with the sea chest valve was stiffened by three brackets across the coupling.

*References are listed on page 36.

The broad objectives of the underway trial on OKINAWA were:

1. To determine the vibratory characteristics of the hull, island, radar mast, machinery, and weapon system due to variable force excitation.

2. To collect data from which damping of the hull could be determined.

3. To provide information for use in determining specifications and design criteria for the LPH Class.

In order to meet the above objectives, vibrations were recorded on OKINAWA during steady-state speed runs, ship maneuvers, and anchor drop tests. Measurements were concentrated on the hull, main propulsion machinery, island, radar mast, and the Mark 63 Director 2 mounted on the island. The data were recorded both on a string oscillograph and on magnetic tapes.

Preliminary analysis of the vibration data (reported by letter) emphasized the measurements obtained at the director; its relocation (the base had been mounted on the island 06 level prior to the trial) had little effect on the vibration of the director at blade rate. The data further indicated that vibration levels in the athwartship direction at the top of the island (07 level) were magnified up to a factor of 8 relative to the bottom of the island (03 level) for speeds above 85 rpm. Maximum blade frequency amplitudes at the fantail were given and compared with levels measured by Philadelphia Naval Shipyard during builder's trials.

The more detailed vibration analysis reported in a later letter showed that the rather large magnification of vibration motions of the island relative to the hull suggested one or both of the following possible causes: (1) the island structure above the main deck was too compliant in the athwartship direction or (2) the attachment of the island structure to the flight deck or the rigidity of the flight deck-hull combination in the vicinity of the island was insufficient. Vibration calculations of the main propulsion system revealed that the replacement of the four-bladed propeller with either a five-bladed or three-bladed propeller could not be expected to solve the problem of excessive island-radar mast vibration on OKINAWA. Consequently, a redesign study of the island-radar mast structure was initiated at the Bureau of Ships. This led to a recommended change in the topmast for all ships of the LPH-2 Class. (This information was presented in Bureau of Ships letter Serial 442-M9 of 18 February 1964.) The present summary report does not include any further analytical information on the island-radar mast structure.

The maximum levels of vibration were determined by a visual analysis of oscillogram records taken during steady-speed runs and ship maneuvers, such as crashbacks and hard turns. The vibration levels of the radar mast were reported in Reference 1. In Reference 2, a maximum value analysis was applied to determine the maximum vertical and athwartship vibrations at blade frequency for the hull of OKINAWA during steady-speed runs.

The present report summarizes the maximum vibrations measured during ship maneuvers. The measured vertical and athwartship hull frequencies are compared with the hull vibration calculations reported in Reference 3, and the longitudinal vibrations of the main propulsion machinery are compared with calculations of the propeller-shafting-machinery system. The significance of superstructure vibration on the LPH-2 Class is discussed, and several recommendations are made which provide an input to a program leading to the improved design of superstructures.

CHARACTERISTICS OF SHIP AND PROPELLER

The main ship design characteristics of OKINAWA are as follows:

Length (overall)	L_{OA}	602.3 ft
Length (between perpendiculars)	L_{BP}	556.0 ft
Beam (extreme)	B	84.2 ft
Depth (to main deck, molded)	D	47.2 ft
Draft (full load)	H	26.1 ft
Displacement (design)	Displacement	17,983 tons
Maximum shaft revolutions		118 rpm

The ship appendages consist of one rudder and two bilge keels. The main propulsion machinery consists of a cross-compound, two-casing turbine and condenser. The turbine is connected to the shaft by a double reduction gear.

Figure 1 shows the propeller and adjacent stern area of the ship. The propeller characteristics are as follows:

Number of propellers	1
Diameter = D = 2R	21.0 ft
Pitch at 0.7R	22.5 ft
Pitch ratio (at 0.7R)	1.072
Area ratio (expanded)	0.528
Mean width ratio (MWR)	0.26
Number of blades	4
Direction of rotation	R.H.
Material	Manganese bronze
Weight	46,010 lb

PROCEDURE

INSTRUMENTATION

Velocity pickups (Consolidated Type 4-102A), linear integrating amplifiers (Consolidated System D Type 1-112C), a 36-channel string oscillograph (Consolidated Type 5-119), and two 14-channel tape recorders (Consolidated Type PR-2300 and Type PR-3300) were used to obtain vibratory displacements; see Figure 2.

Velocity pickup signals were integrated to give an output signal proportional to the vibratory displacements. The signals from the gages were recorded on both the oscillograph and tape recorders.

The measuring system was calibrated in the laboratory prior to the underway survey, after the equipment was installed on the ship prior to the trials, and at periodic intervals during the trials. The laboratory calibration was evaluated and a conversion factor curve (Figure 3) obtained. Calibration on board the ship consisted of voltage signals simulating the output of the velocity gages. A calibration signal of 206 mv peak to peak at 15 cps was used to simulate the output of the velocity gages when subjected to 20 mils (0.020 in.) peak to peak displacement at 15 cps.

The gage locations are shown in Figures 4, 5, and 6 and are listed in Table 1. Only 12 channels of data could be recorded simultaneously on each tape recorder since two channels of each recorder were used for shaft rpm and voice identification. The vibrations were therefore recorded in two phases; the vertical hull gage at Frame 135 was a common reference between the phases. The first phase consisted of all the gages on the hull, island, and mast, and two main propulsion machinery components (thrust bearing and thrust-bearing foundation); the second phase consisted of the gages on the gun director, three roving gages placed at various positions, and two machinery components (condenser and flexible coupling).

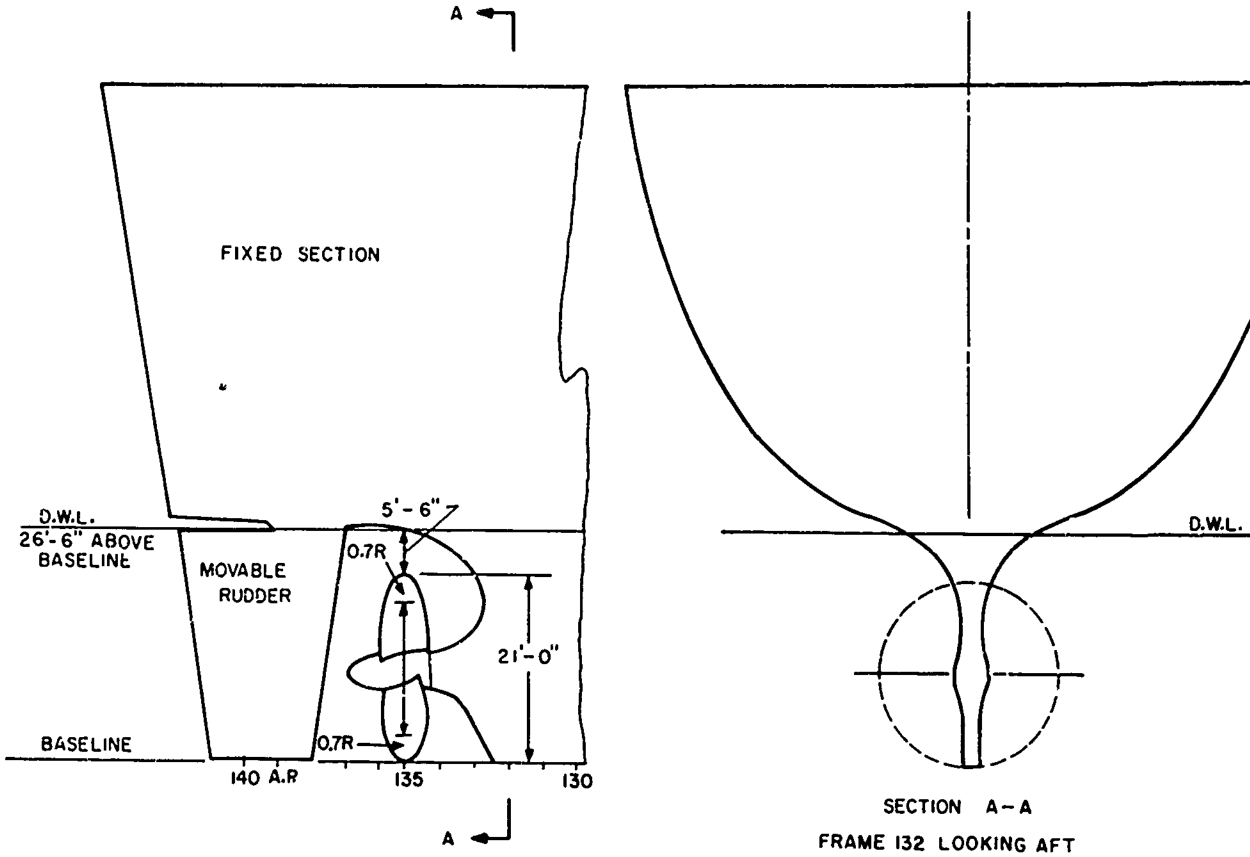


Figure 1 – Propeller and Adjacent Stern Area

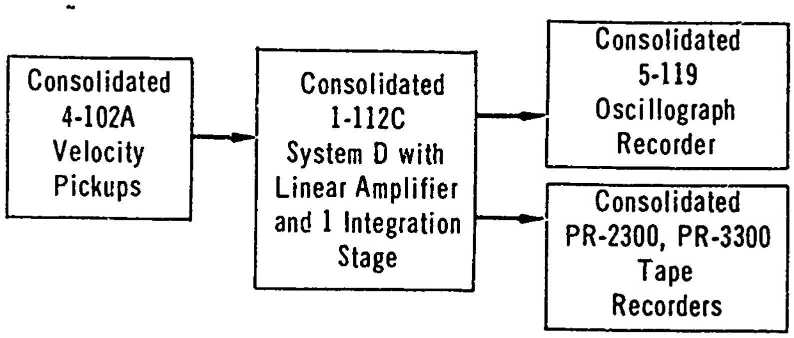


Figure 2 – Instrumentation System

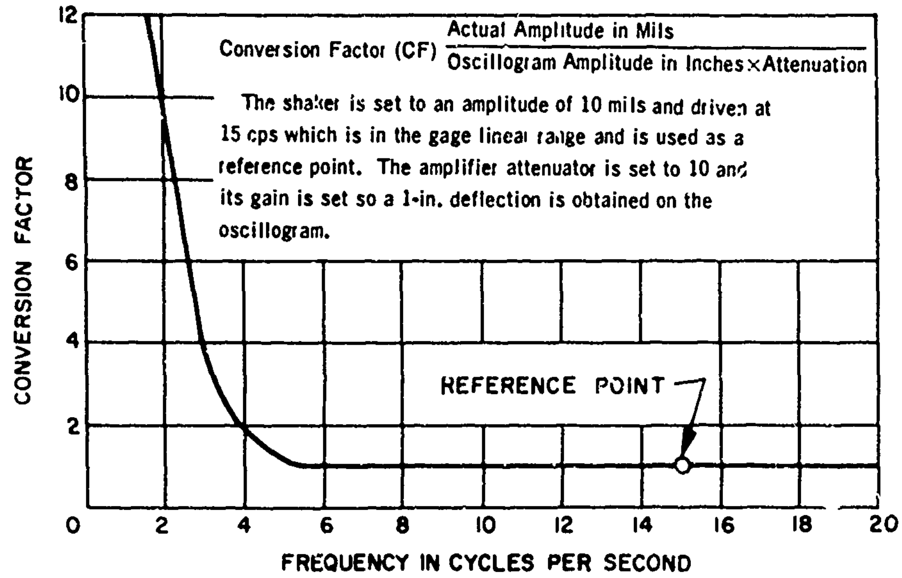


Figure 3 – Conversion Factor Curve for Velocity Gages

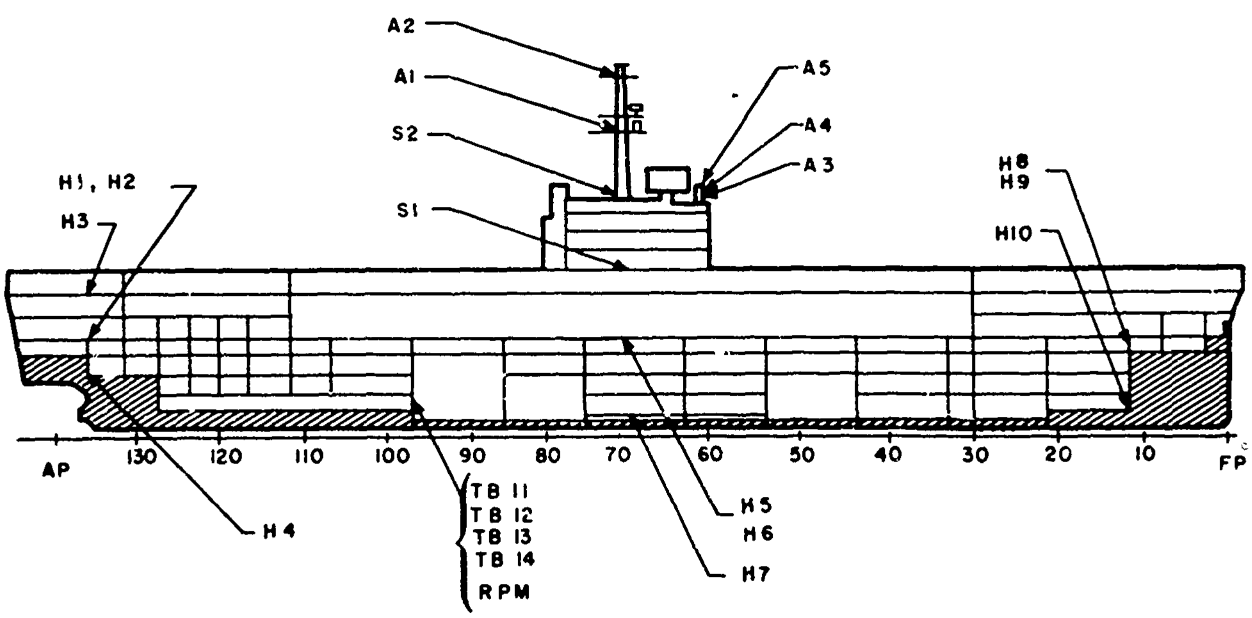


Figure 4 – Inboard Profile of OKINAWA Showing Location of Velocity Gages

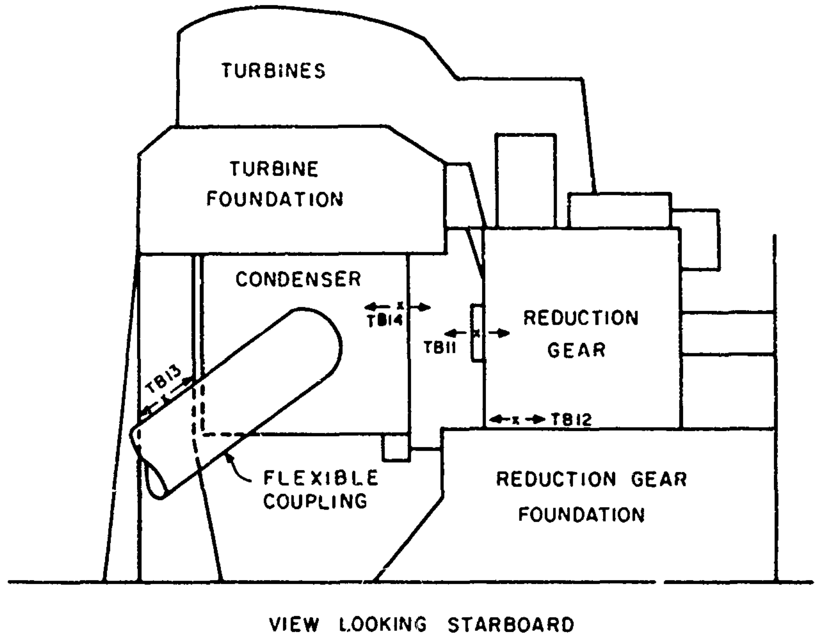


Figure 5 – Gage Locations on Main Propulsion Machinery

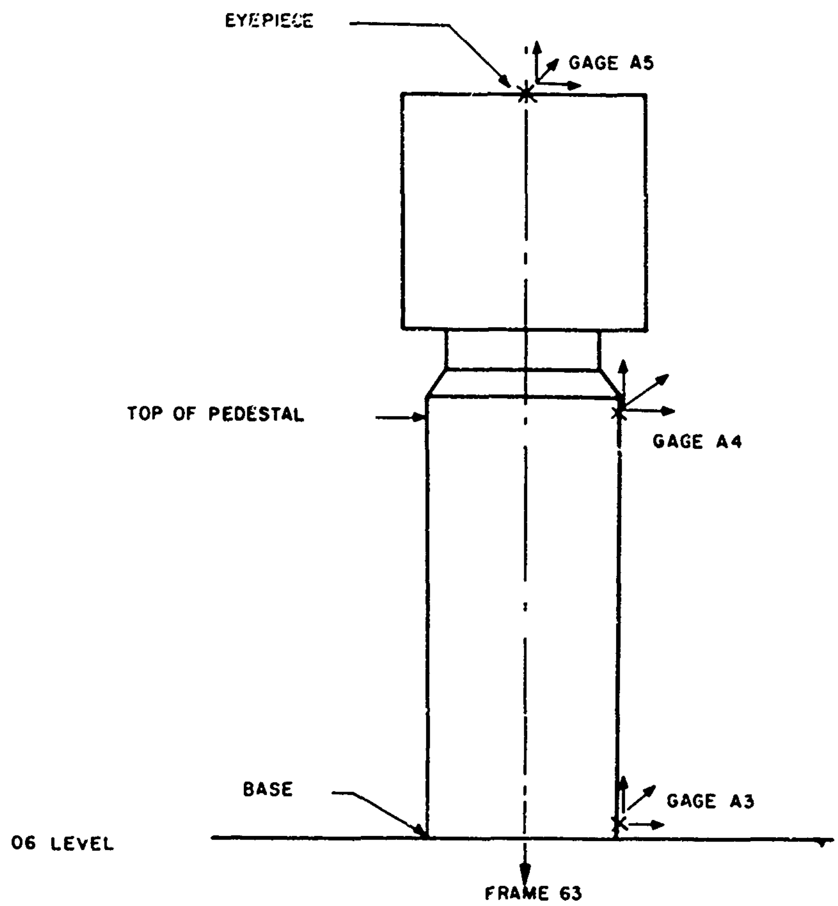


Figure 6 – Gage Locations on Mark 63 Director 2

NOTE: For direction of measurements, see Table 1.

TABLE 1

Measurement Locations

Position No.*	Frame	Deck	Description of Location
H1(V)	135	1	Centerline above propeller
H2(A)	135	1	Centerline above propeller
H3(A)	135	02	Centerline above propeller
H4(A)	135	3	Centerline above propeller
H5(V)	67	1	1 Port 1 Starboard
H6(A)	67	1	Centerline
H7(A)	67	5	Centerline
H8(V)	13	1	Centerline
H9(A)	13	1	Centerline
H10(V)	13	5	Centerline
TB11(L)			Thrust bearing
TB12(L)			Thrust-bearing foundation
TB13(L)			Flexible coupling
TB14(L)			Condenser
S1(VA)	67	03	At base main mast
S2(VAL)	67	07	At mast – 07 level
A1(AL)	67		At mast – 30 ft above 07 level
A2(AL)	67		At topmast – 58 ft above 07 level
A3(VAL)	63	06	Base Mark 63 Director 2
A4(VAL)	63		Top pedestal Mark 63 Director 2
A5(VAL)	63		Eyepiece Mark 63 Director 2

*The letters V, A, L in the parentheses stand for vertical, athwartship, and longitudinal direction, respectively.

TRIAL CONDITIONS

The trials were conducted enroute from Norfolk, Virginia to Guantanamo Bay, Cuba at speeds ranging from 50 to 118 rpm, in water depths of more than 500 ft, and a State 3 to 4 sea. Several helicopters, jeeps, and a number of military personnel were on board, and the ship had a displacement of 17,700 tons (98 percent of design displacement).

Conversations with ship personnel prior to the trial revealed that noticeable vibrations were produced in the stern areas for several decks above a laundry extractor (washer), located on the second deck in the stern. As a result, the extractor was turned off during the trials so that the only sources of vibration excitation were due to propeller-excited forces and wave motion.

Hull transient vibrations were produced by dropping and snubbing the anchor with the ship stationary (zero speed). The subsequent motions were recorded on both the oscillograph and the magnetic-tape recorders.

DATA ANALYSIS

Manual (visual) procedures[4] were used to obtain the maximum blade frequency amplitudes of vertical and athwartship vibration measured at the fantail (Frame 135, main deck centerline) during steady-speed runs. The amplitudes of shaft frequency vibration components (which were excited only at higher ship speeds) could not easily be determined by visual analysis of the oscillogram records. Hence, electronic analysis of the tape records was used to determine the major components of fantail vibration excited during steady-speed runs.

The average amplitudes of propeller-excited fantail vibration were obtained by an analysis of the tape recordings on a Technical Products Company TP-625 Analyzer System. The tape records obtained during the steady-speed runs were transferred to a loop tape for analysis at a speed 32 times faster than the recording speed. By using a 5-cps bandwidth filter and increasing the loop speed, an "effective" filter bandwidth of 5/32 cps was achieved.

Values of damping coefficients for hull vertical vibration were derived from the anchor drop tests. A visual analysis of oscillogram records was used to obtain values for the first two vertical hull modes. Since estimates of hull damping and modes are increasingly difficult to obtain from oscillograph records for modes above the fundamental hull frequency, an electronic analysis of the tape records was also performed.

TEST RESULTS

FREE ROUTE (STRAIGHT COURSE) TESTS

Measurements of the vibrations of the hull, island, and radar mast during steady-speed runs are summarized in Table 2. Vibrations measured on the main propulsion machinery and Mark 63 Director 2 are summarized in Table 3. The measured natural frequencies of the hull are compared with theoretical frequencies in Table 4.

The maximum blade frequency amplitudes of vertical and athwartship vibration measured at the fantail (Frame 135, main deck centerline) during steady-speed runs versus rpm are shown in Figures 7 and 8, respectively. The accelerations corresponding to the fantail vertical and athwartship maximum vibrations during steady-speed runs are given in Figures 9 and 10, respectively.

The average amplitudes of shaft frequency, blade frequency, and the first two harmonics of vertical and athwartship vibration at blade frequency at the fantail as determined by narrow bandwidth filtering are shown in Figures 11 and 12, respectively.

Maximum amplitudes of blade frequency and double blade frequency vibrations of the island-radar mast structure determined from visual analysis of the oscillogram records are shown in Figures 13 through 15. The maximum amplitudes of athwartship blade frequency vibration of the island-radar mast are summarized in Figure 15a. The athwartship vibration amplitudes at the topmast (58 ft above island 07 level), at the service platform (30 ft above island 07 level), and at the top of the island (07 level) showed large amplification relative to athwartship amplitudes at the base of the island (03 level) at ship speeds above 85 rpm.

The plot of maximum athwartship amplitudes at blade frequency versus rpm (Figure 15a) revealed the presence of a peak athwartship vibration of the mast at 115 rpm (7.7 cps). The amplitude profile of athwartship vibration of the island-mast structure at blade frequency measured at 115 rpm is shown in Figure 16.

Maximum amplitude components of propeller-blade-excited vibration measured on the Mark 63 Director 2 are given in Figures 17 through 19. The vertical vibration amplitudes at blade rate measured on the director at the base, pedestal, and eyepieces are plotted versus shaft rpm in Figure 17. The athwartship vibration amplitudes at the director base, pedestal, and eyepiece at blade rate versus shaft rpm are shown in Figure 18. The longitudinal blade rate vibrations of the director are shown in Figure 19. The blade rate amplitudes at the three locations of the director showed an increase in amplitude from the base to the eyepiece which was nearly independent of the direction measured. The measured amplitudes for the three directions and the three gage locations are listed in Table 5 for those frequencies at which considerable magnification could be observed. These frequencies should be considered as pertinent to the director.

The maximum longitudinal vibration amplitudes at blade rate and double blade rate measured on the main propulsion machinery are presented in Figures 20 and 21, respectively. Maximum longitudinal blade frequency amplitudes are summarized in Table 6, and calculations of shaft-machinery frequencies are given in Appendix A.

TABLE 2

Underway Measurements of Maximum Vibratory Displacements of Hull, Island, and Radar Mast during Free Route (Straight Course) Runs

Gage Location	Vertical Vibration				Athwartship Vibration			
	Gage No.	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils	Gage No.	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils
Hull, Bow Frame 13	H8V	118 50	7.7H* 3.3BF	0.5 0.5	H9A	115 75	7.6H 5.0BF	1.5 2.8
Hull, Main Deck Frame 67, Port	$H5V_p$	118	7.7H	0.9	- -	-	-	-
Hull, Main Deck Frame 67, Starboard	$H5V_s$	118	7.7H	0.9		-	-	-
Hull, Main Deck Frame 67, Centerline	-	-	-	-	H6A	115 75	7.6H 5.0BF	0.7 1.0
Hull, Stern Frame 135	H1V	118	7.7H	2.4	H2A	115	7.6H	3.2
Island (07 level)	S2V	118 110	7.7H 7.3BF	2.6 1.9	S2A	118 115	7.7H 7.6BF	17.4 13.0
Island (03 level)	S1V	115 110	7.7H 7.3BF	1.9 1.2	S1A	118 105	7.7H 7.0BF	4.0 3.8
Radar Mast (58 ft above 07 level)	-	-		-	A2A	115	7.6H	31.2
Radar Mast (30 ft above 07 level)	-	-	-	-	A1A*	118 115	7.7H 7.6BF	28.8 27.8

*H indicates hull modes, BF indicates blade frequency.

TABLE 3

Underway Measurements of Maximum Vibratory Displacements of Mark 63 Director 2 and Main Propulsion Machinery during Free Route (Straight Course) Runs

Gage Location	Vertical Vibration				Athwartship Vibration				Longitudinal Vibration			
	Gage No	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils	Gage No.	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils	Gage No.	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils
Director Base Frame 63	A3V	50 65 115	3.3BF* 4.3BF 7.7BF	1.5 0.4 2.3	A3A	55 65 115	3.7BF 4.3BF 7.7BF	8.0 2.0 18.0	A3L	55 65 115	3.7BF 4.3BF 7.7BF	1.2 0.4 3.4
Director Top Pedestal Frame 63	A4V	50 65 115	3.3BF 4.3BF 7.7BF	1.6 0.5 3.5	A4A	55 65 115	3.7BF 4.3BF 7.7BF	9.0 2.0 22.0	A4L	50 65 115	3.3BF 4.3BF 7.7BF	2.1 0.9 4.6
Director Eyepiece Frame 63	A5V	55 65 115	3.7BF 4.3BF 7.7BF	4.5 9.0 13.0	A5A	55 65 115	3.7BF 4.3BF 7.7BF	32.0 17.0 73.0	A5L	50 65 105	3.3BF 4.3BF 7.0BF	7.8 7.3 7.4
Thrust-Bearing Foundation	-	-	-	-	-	-	-	-	TB12L	65 65 118	4.3BF 8.7L 7.9BF	1.4 0.7 5.4
Thrust Bearing	-	-	-	-	-	-	-	-	TB11L	65 65 118	4.3BF 8.7L 7.9BF	2.4 1.2 9.0
Condenser	-	-	-	-	-	-	-	-	TB14L	65 65 118	4.3BF 8.7L 7.9BF	2.8 2.2 8.3
Flexible Coupling	-	-	-	-	-	-	-	-	TB13L	65 65 118	4.3BF 8.7L 7.9BF	1.9 2.0 11.8

*BF indicates blade frequency L indicates fundamental longitudinal mode of main propulsion machinery.

TABLE 4

Comparison of Experimental and Theoretical Frequencies of Vertical and Athwartship Modes of Hull Vibration

Modes	Experimental* (17,700-ton loading)	Theoretical** (18,482-ton loading)
Vertical		
First	1.9	1.9
Second	3.1	3.2
Third	4.2	4.6
Fourth	5.4	6.0
Fifth	6.6	7.4
Sixth	7.9 †	8.6
Athwartship		
First	2.2	2.0
Second	3.8	4.2
Third	5.8	6.9

* Experimental values determined from anchor drop tests (e.g., Figures 24 and 25).

** Theoretical values given here were computed by the electric analog for a heavy displacement and have been corrected for the loading of the ship during the trial. Computed frequencies and modes for both heavy and light displacement conditions are given in Reference 3.

† Experimental determination of frequency uncertain.

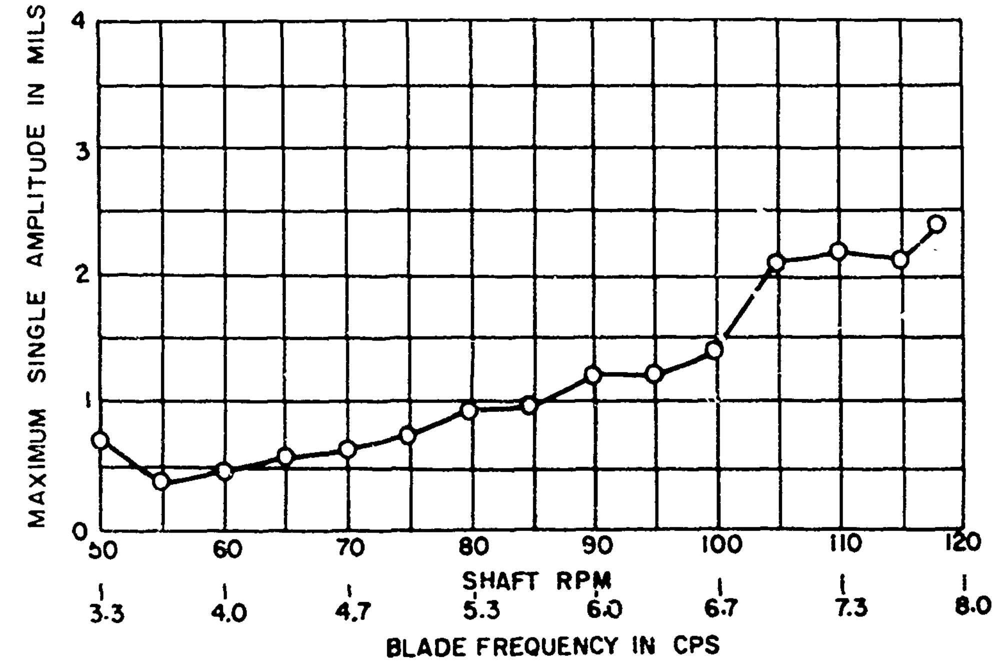


Figure 7 – Vertical Blade Rate Vibration Amplitudes on OKINAWA at Centerline of Main Deck, Frame 135, during Steady-Speed Runs versus Shaft RPM

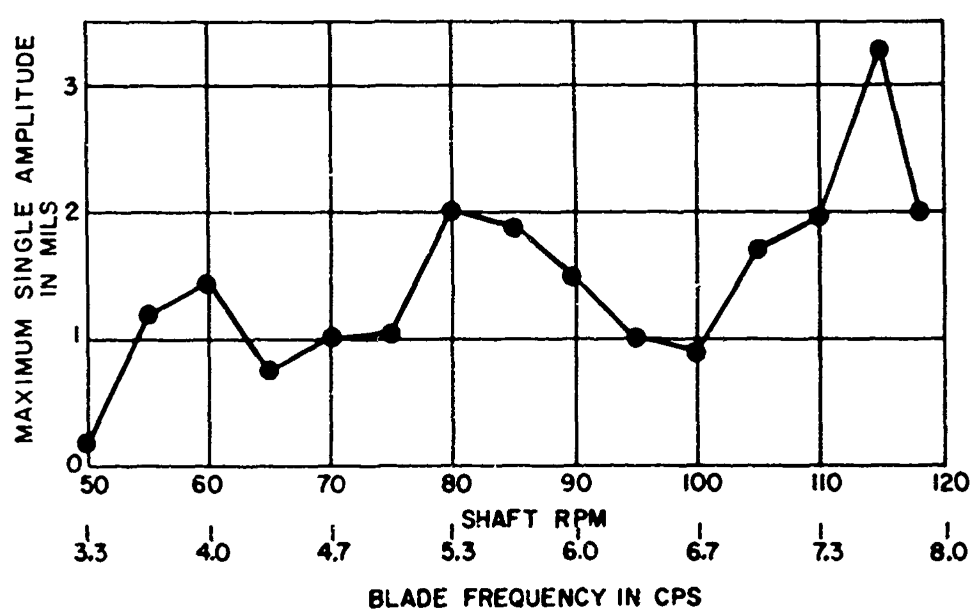


Figure 8 – Athwartship Blade Rate Vibration Amplitudes on OKINAWA at Centerline of Main Deck, Frame 135, during Steady-Speed Runs versus Shaft RPM

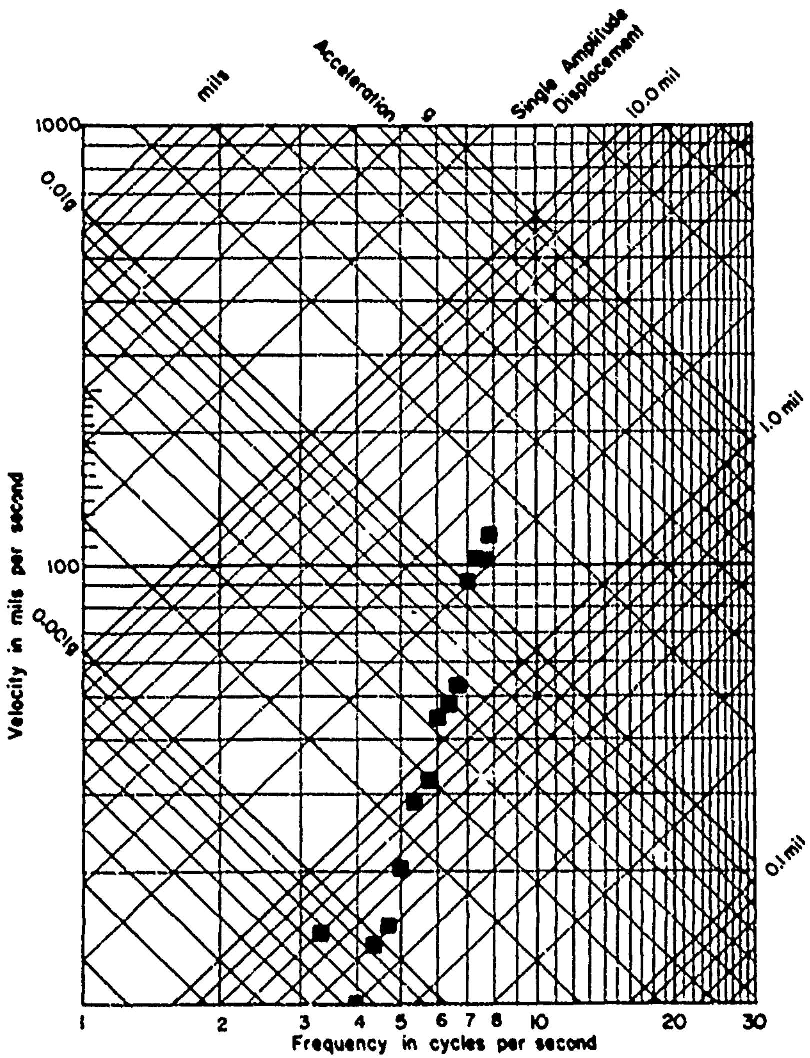


Figure 9 – Vertical Hull Vibration Accelerations at Fantail during Steady-Speed Runs

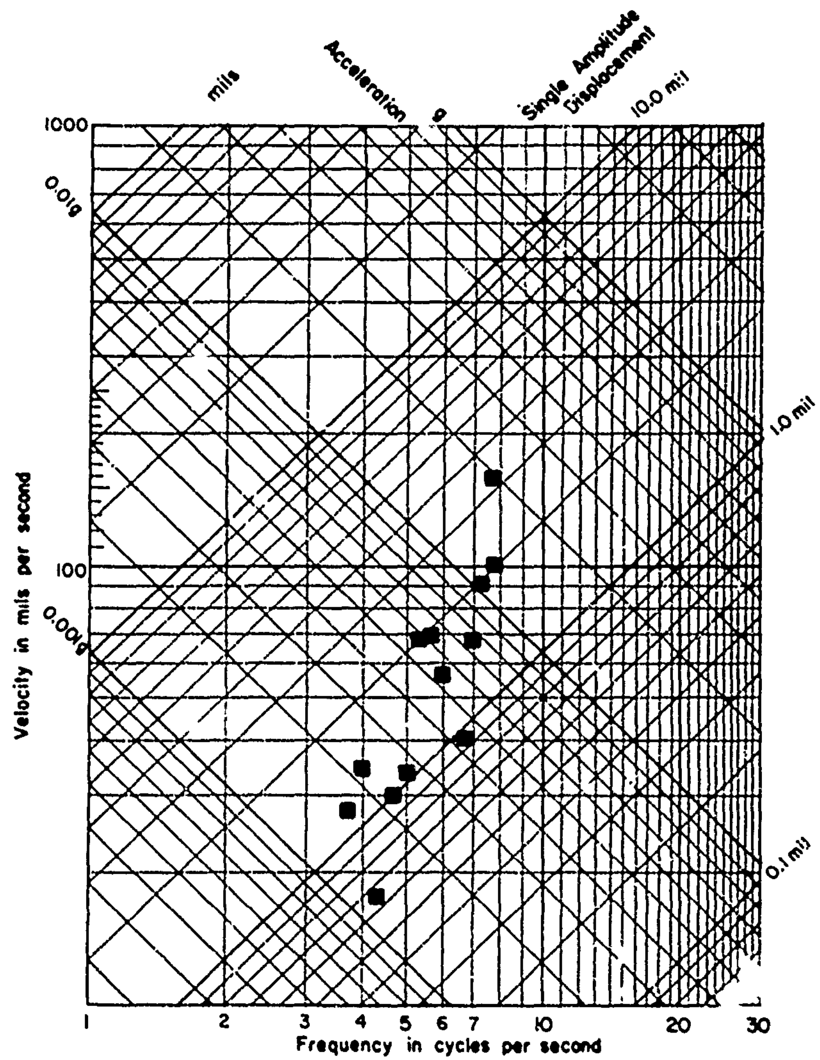


Figure 10 – Athwartship Hull Vibration Accelerations at Fantail during Steady-Speed Runs

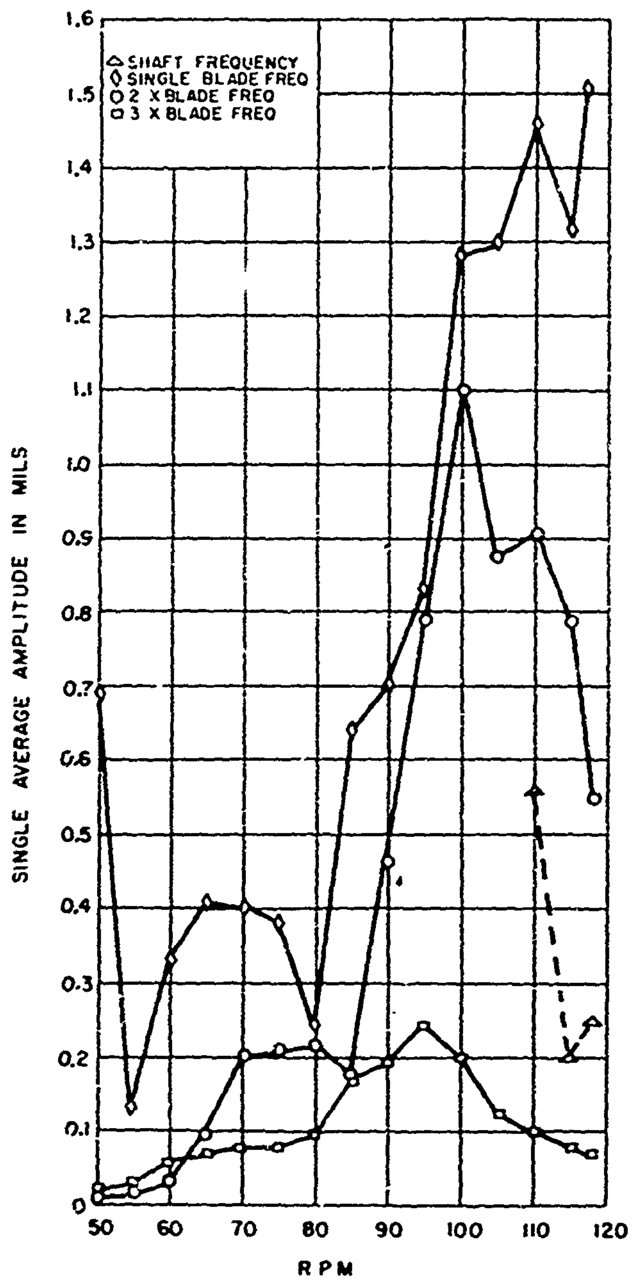


Figure 11 – Average Amplitude Components of Propeller-Excited Vertical Vibration at Fantail during Steady-Speed Runs

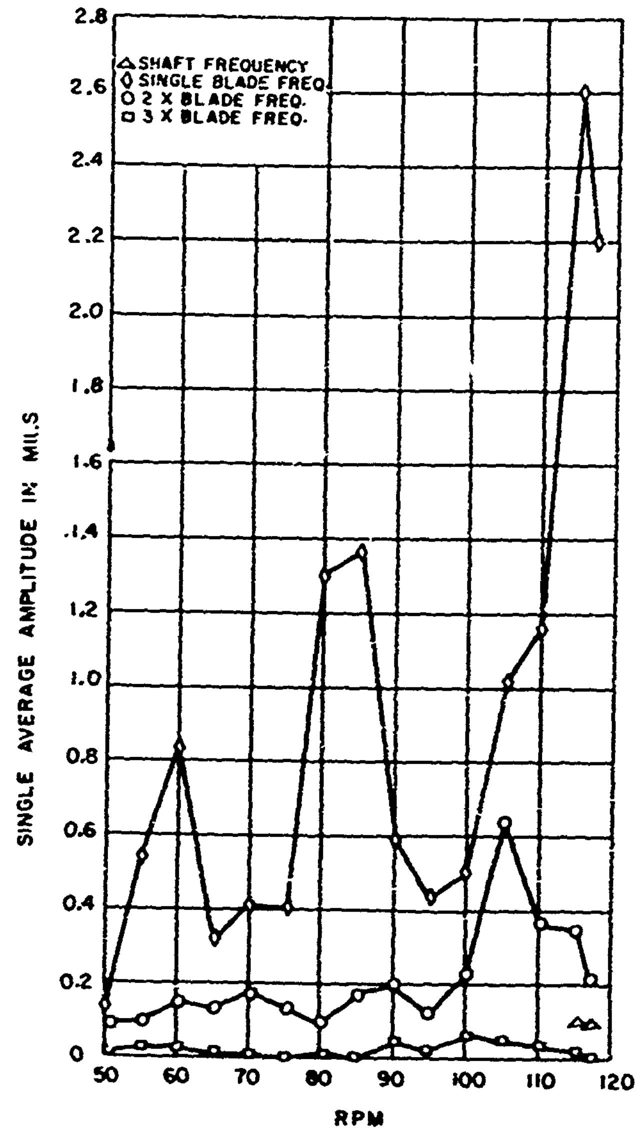


Figure 12 – Average Amplitude Components of Propeller-Excited Athwartship Vibration at Fantail during Steady-Speed Runs

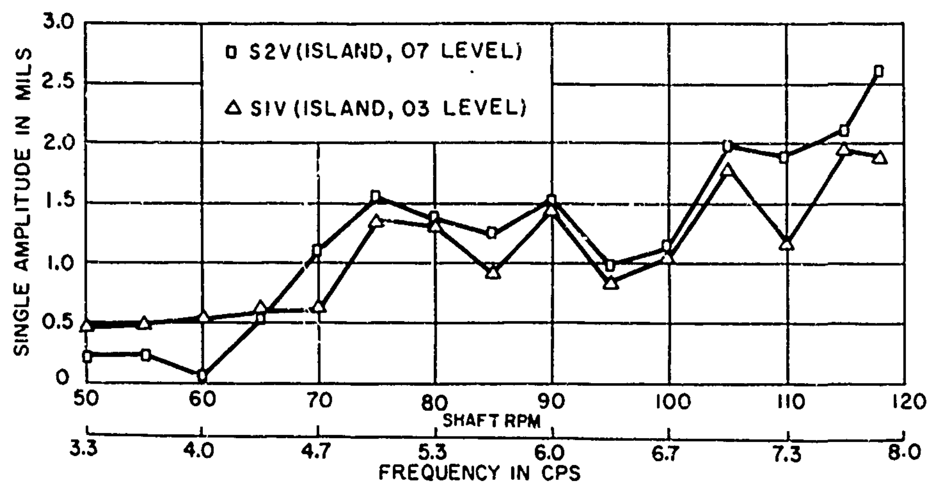


Figure 13a – Maximum Amplitudes of Blade Frequency Components

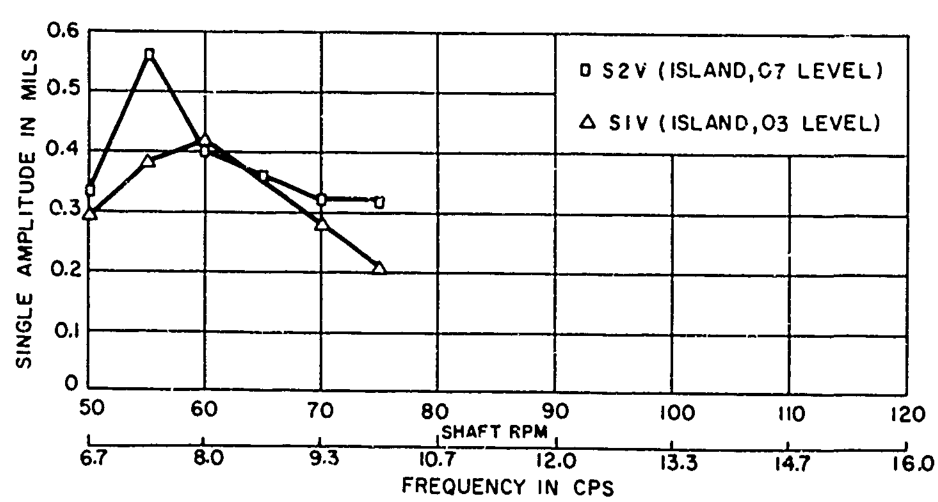


Figure 13b – Maximum Amplitudes of Double Blade Frequency Components

Figure 13 – Maximum Amplitudes of Vertical Vibration of the Island Structure during Steady-Speed Runs

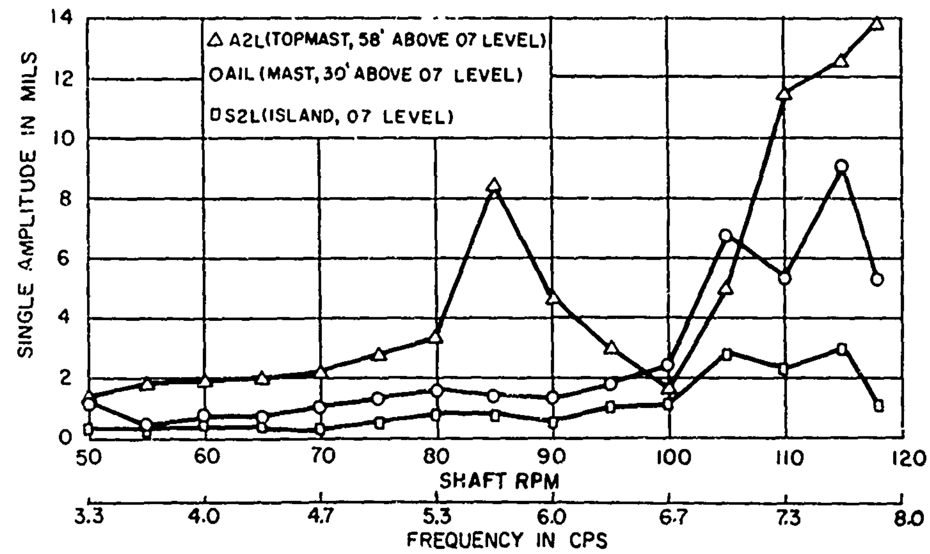


Figure 14a – Maximum Amplitudes of Blade Frequency Components

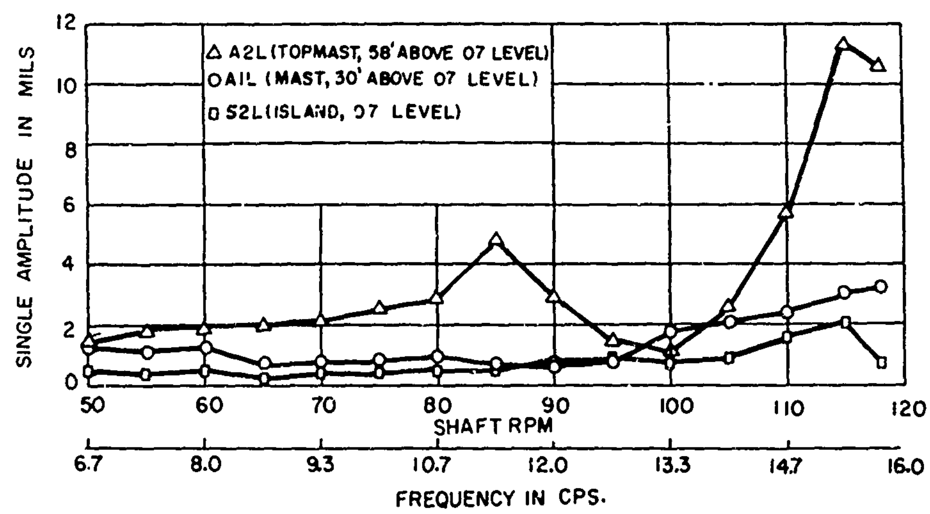


Figure 14b – Maximum Amplitudes of Double Blade Frequency Components

Figure 14 – Maximum Amplitudes of Longitudinal Vibration of the Island-Radar Mast Structure during Steady-Speed Runs

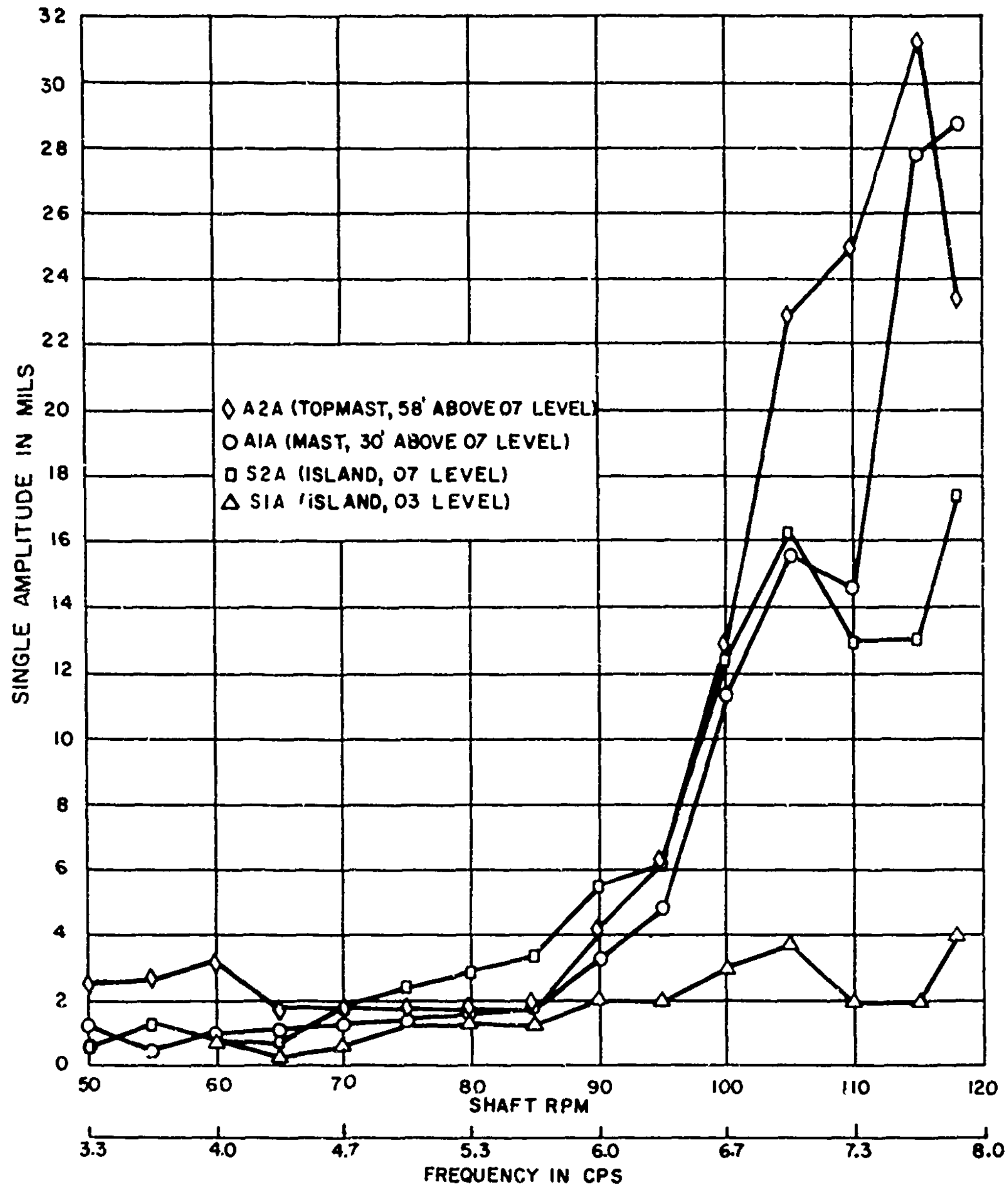


Figure 15a – Maximum Amplitudes of Blade Frequency Components

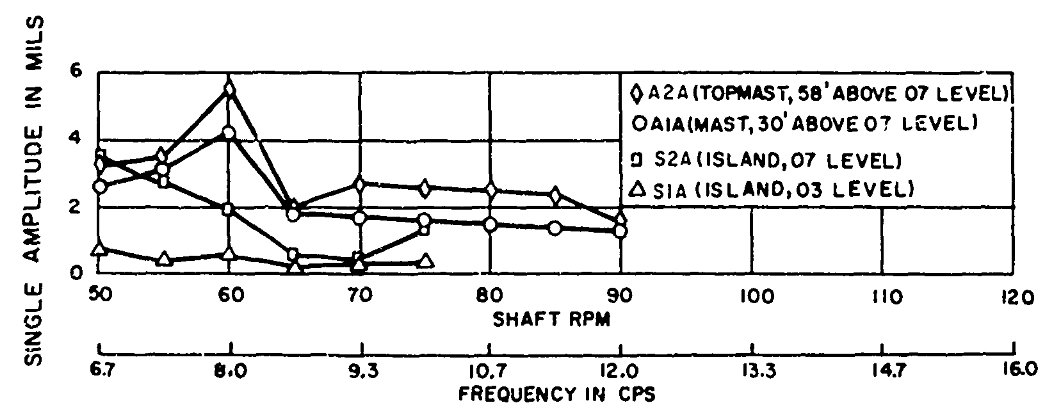


Figure 15b – Maximum Amplitudes of Double Blade Frequency Components

Figure 15 – Maximum Amplitudes of Athwartship Vibration of the Island-Radar Mast Structure during Steady-Speed Runs

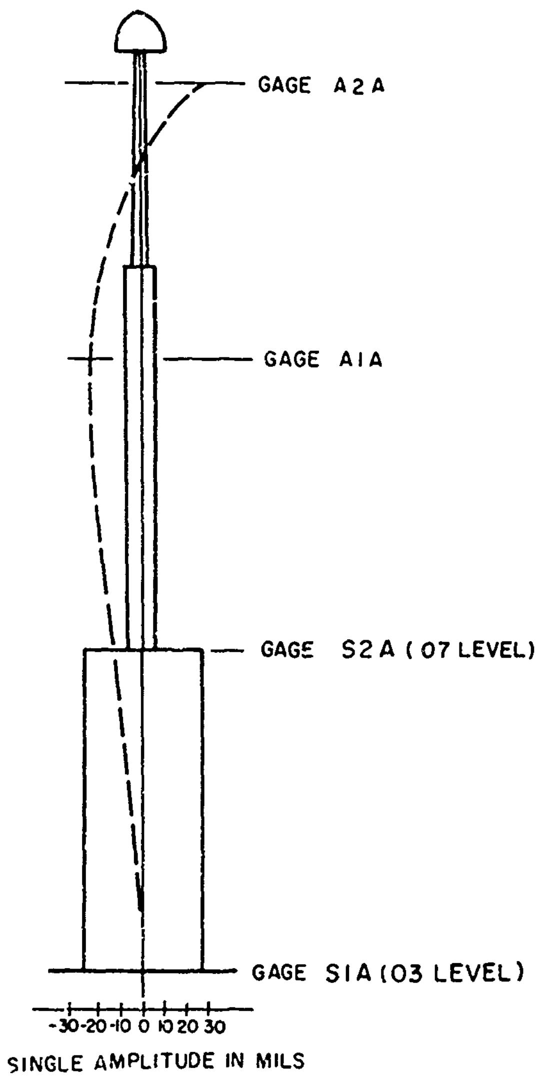


Figure 16 – Amplitude Profile of Athwartship Vibration of the Island-Mast Structure at Blade Frequency at 115 RPM

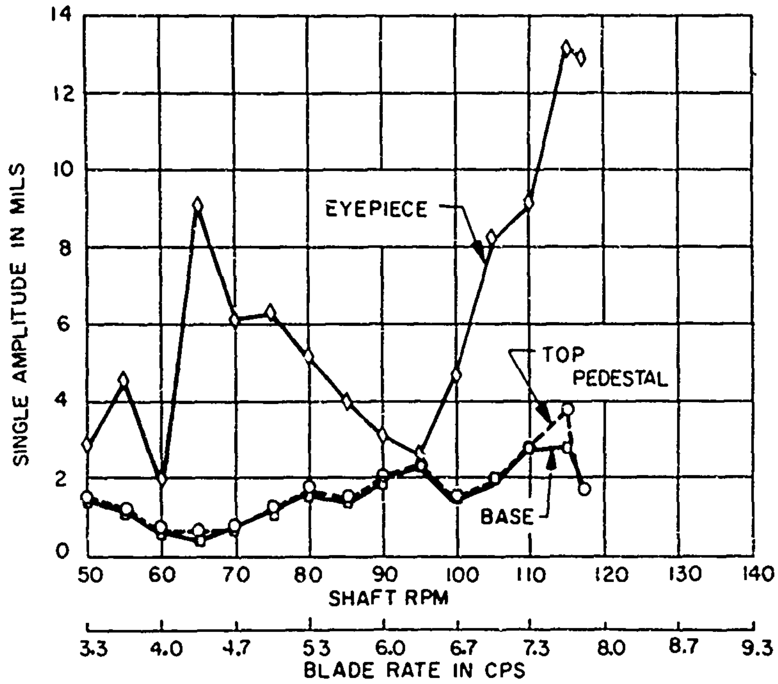


Figure 17 – Vertical Vibration Amplitudes at Blade Rate versus Shaft RPM at Mark 63 Director 2

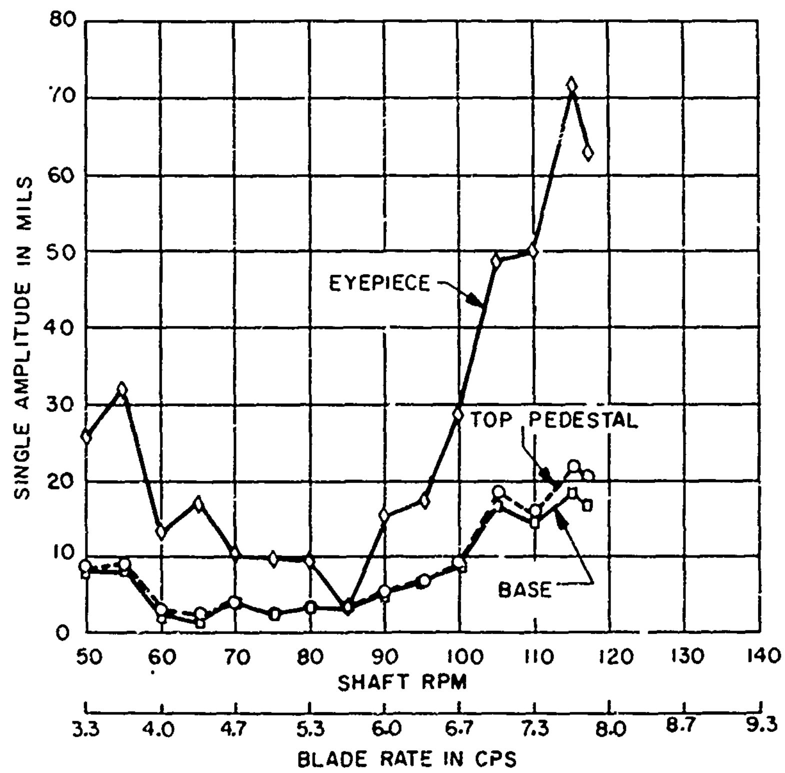


Figure 18 – Athwartship Vibration Amplitudes at Blade Rate versus Shaft RPM at Mark 63 Director 2

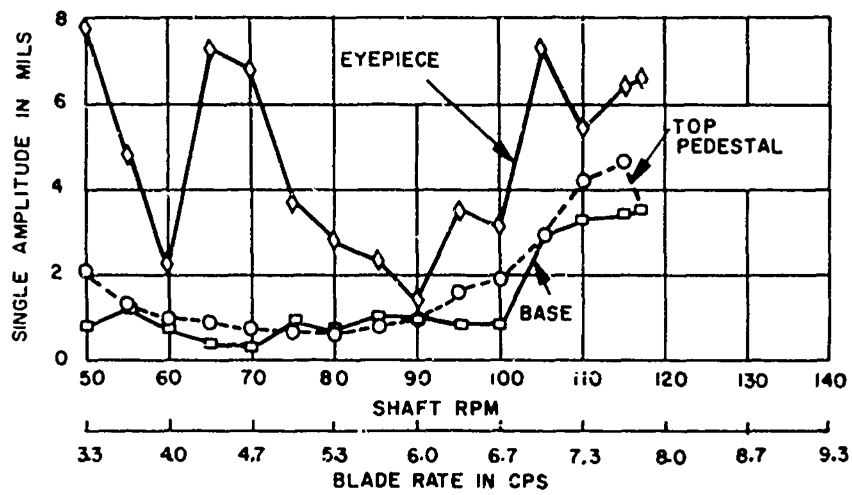


Figure 19 – Longitudinal Vibration Amplitudes at Blade Rate versus Shaft RPM at Mark 63 Director 2

TABLE 5

Maximum Amplitudes at the Natural Frequencies of the Director

Location	Direction	1963* Amplitude mils	Magnification as Compared to Base 1963 Trial	1962** Amplitude mils
Eyepiece	V	4.5/9/13	4.5/22.5/4.7	-/-/10
	A	32/17/73	4/8.5/4	-/-110
	L	4.8/7.3/6.4	4/18/2	-/-/19
Top Pedestal	V	1/0.5/3.5	1	-/-/2
	A	9/2/22	1	-/-/12
	L	1.3/0.9/4.6	1	-/-/4
Base	V	1/0.4/2.8	1	-/-/1.5
	A	8/2/28	1	-/-/12.5
	L	1.2/0.4/3.4	1	-/-/2.5

*Amplitudes are given at 3.7, 4.4, and 7.7 cps for all directions.

**Only values for the highest frequency are available.

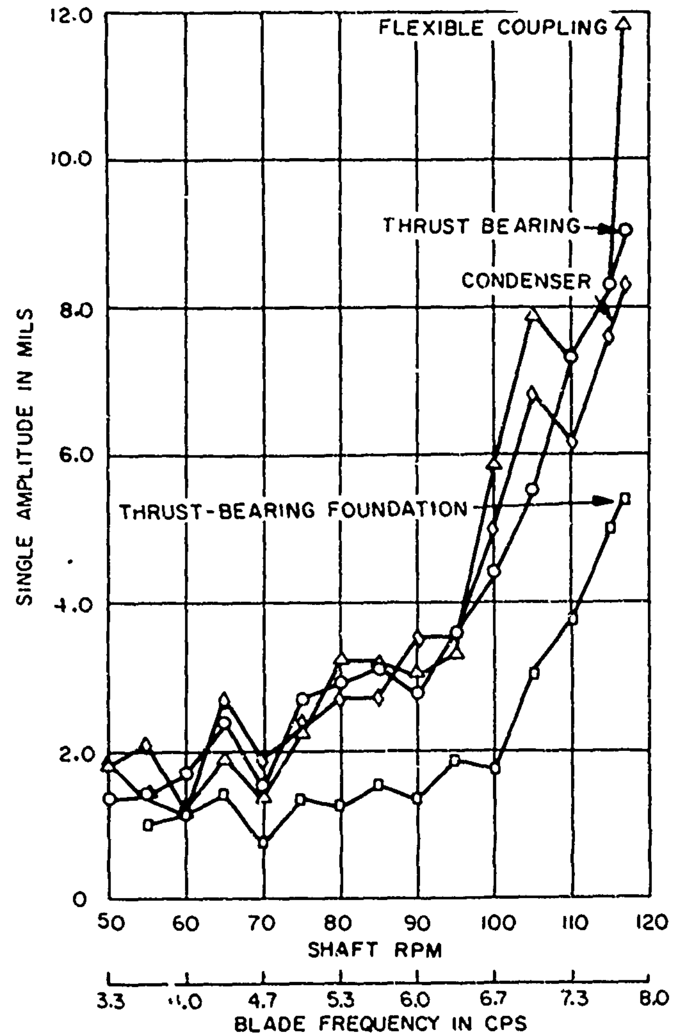


Figure 20 – Maximum Amplitudes of Longitudinal Blade Frequency Vibration of the Main Propulsion Machinery Components

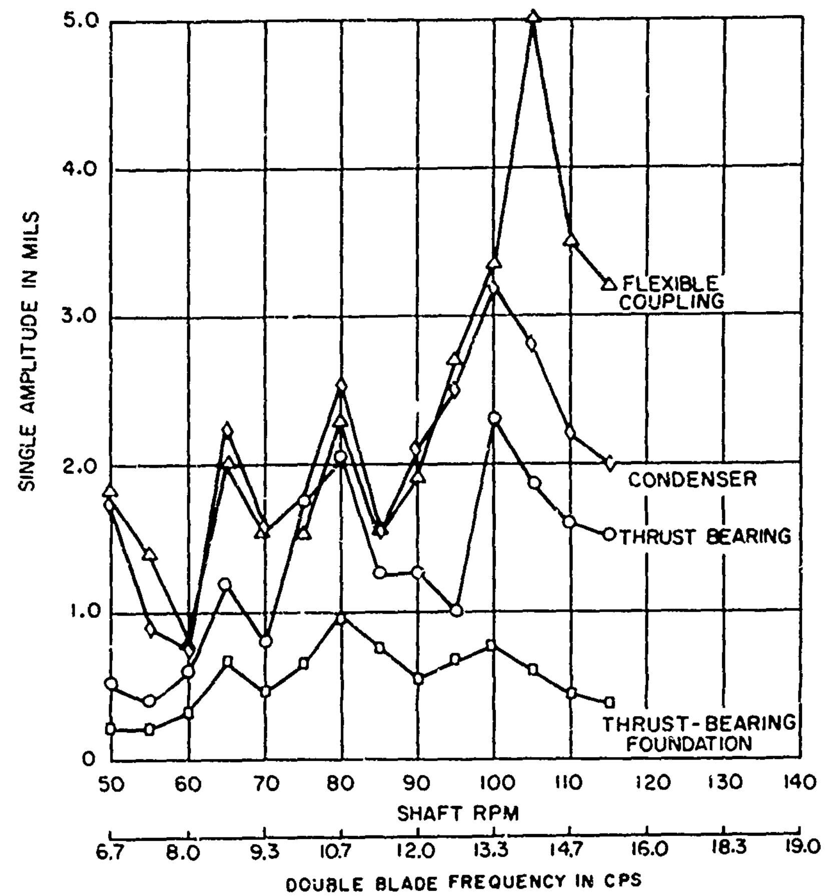


Figure 21 – Maximum Amplitudes of Longitudinal Double Blade Frequency Vibration of the Main Propulsion Machinery Components

The corresponding values obtained (by Philadelphia Naval Shipyard during builder's trials in May 1962) prior to stiffening of the flexible coupling are included in Table 6 for comparison. At 65 rpm (8.7-cps double blade frequency), all four of the measured machinery components vibrated in phase. At 80 rpm (10.7 cps double blade frequency), the flexible coupling vibrated out of phase with the other machinery components. At 100 rpm (13.3-cps double blade frequency), the condenser and flexible coupling vibrated out of phase with respect to the thrust bearing and thrust-bearing foundations.

MANEUVERING TESTS

Tables 7 through 10 summarize the vibration levels of the hull, island, mast, main propulsion system, and Mark 63 Director 2 which were measured during ship maneuvers. The maximum vibratory displacements measured during hard turns to port are presented in Table 7. Maximum vibrations during hard starboard turns are given in Table 8. Maximum vibrations recorded during the crashback maneuver (full speed ahead to full speed astern) are summarized in Table 9. Table 10 lists the magnification factors of the island-radar mast structure measured at Positions A2, A1, S2, and S1 in the athwartship and longitudinal direction during crashback maneuvers and hard turns to port and starboard.

The vibrations measured at various positions during the starboard turns were generally greater than those measured during port turns by an average factor of 1.3 to 1.4, regardless of the direction of motion.

ANCHOR DROP TESTS

The anchor drop tests were included to identify hull modes of vibration and to obtain data from which to estimate hull damping values. The estimation of hull damping coefficients assumes particular importance in computer programs for hull response, since presently employed damping coefficients are based on the average values of damping measured on a number of ships which vary considerably with the type of ship and mode of vibration.[5]

The values of logarithmic decrements for the first two vertical hull modes obtained by visual analysis of oscillogram records were 0.016 at 1.9 cps and 0.038 at 3.1 cps, respectively

Table 11 gives estimates of damping coefficients for the first four vertical hull modes obtained by the electrical-graphical technique described in Appendix B. The values obtained by visual analysis of the oscillograph records are included for purposes of comparison.

The principal results of the underway vibration tests are summarized in a vibration data sheet (Appendix C).

DISCUSSION

Hull vertical resonances were identified at 1.9, 3.1, 4.2, 5.4, and 6.6 cps; the sixth mode was uncertain. Athwartship hull vibration resonances were identified at 2.2, 3.8, and

TABLE 6

Maximum Longitudinal Blade Frequency Vibrations of the Main Propulsion Machinery

Component	Trial Date					
	March 1963			May 1962 (Measured by Philadelphia Naval Shipyard)		
	Shaft RPM	Frequency cps	Single Amplitude mils	Shaft RPM	Frequency cps	Single Amplitude mils
Thrust Bearing	118	7.9	9	118	7.9	10
Thrust-Bearing Foundation	118	7.9	5.4	118	7.9	5.5
Condenser	118	7.9	8.3	118	7.9	11
Flexible Coupling	118	7.9	11.8	118	7.9	13

TABLE 7

Underway Measurements of Maximum Vibratory Displacements of Hull, Island, Radar Mast, Main Propulsion Machinery, and Mark 63 Director 2 during Hard Port Turn

Gage Location	Vertical Vibration			Athwartship Vibration			Longitudinal Vibration		
	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils
Hull Stern Frame 135	107	7.1BF*	6.5	115	7.7BF	9.5	-	-	-
Island 03 level	108	7.2BF	7.5	100	6.7BF	12.5	-	-	-
Island 07 level	113	7.5BF	7.9	106	7.1BF	60.4	110	7.3BF	10.5
Radar Mast 30 ft above 07 level	-	-	-	113	7.5BF	56.1	106	7.1BF	22.5
Radar Mast 58 ft above 07 level	-	-	-	113	7.5BF	73.5	99	6.6BF	112.0
Thrust-Bearing Foundation	-	-	-	-	-	-	118	7.9BF	12.2
Thrust Bearing	-	-	-	-	-	-	118	7.9BF	8.0
Condenser	-	-	-	-	-	-	112	14.9 2BF**	14.7
Flexible Coupling	-	-	-	-	-	-	110	14.7 2BF	15.8
Director Base Frame 63	99	6.6BF	8.6	104	6.9BF	52.3	107	7.1BF	7.7
Director Top Pedestal Frame 63	99	6.6BF	7.5	104	6.9BF	63.8	115	7.7BF	12.0
Director Eyepiece Frame 63	115	7.7BF	24.5	115	7.7BF	122.7	114	7.6BF	43.8

*BF indicates blade frequency.
**2BF indicates double blade frequency.

TABLE 8

Underway Measurements of Maximum Vibratory Displacements of Hull, Island, Radar Mast, Main Propulsion Machinery, and Mark 63 Director 2 during Hard Starboard Turn

Gage Location	Vertical Vibration			Athwartship Vibration			Longitudinal Vibration		
	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils	Shaft RPM	Frequency of Vibration cps	Single Amplitude mils
Hull, Stern Frame 135	118	7.9BF*	5.6	113	7.5BF	13.2	-	-	-
Island 03 level	109	7.3BF	10.1	107	7.1BF	16.6	-	-	-
Island 07 level	109	7.3BF	11.1	107	7.1BF	83.3	109	7.2BF	14.7
Radar Mast 30 ft above 07 level	-	-	-	109	7.3BF	84.3	113	7.5BF	66.9
Radar Mast 58 ft above 07 level	-	-	-	109	7.3BF	100.0	113	7.5BF	164.0
Thrust-Bearing Foundation	-	-	-	-	-	-	113	7.5BF	17.8
Thrust Bearing	-	-	-	-	-	-	110	7.3BF	8.5
Condenser	-	-	-	-	-	-	112	14.9 2BF**	12.6
Flexible Coupling	-	-	-	-	-	-	106	14.1 2BF	12.6
Director Base, Frame 53	112	7.5BF	12.9	109	7.3BF	70.2	109	7.3BF	8.8
Director Top Pedestal, Frame 63	100	6.7BF	10.3	109	7.3BF	89.4	112	7.5BF	22.0
Director Eyepiece, Frame 53	109	7.3BF	34.3	109	7.3BF	166.8	110	7.3BF	58.3

*BF indicates blade frequency.

**2BF indicates double blade frequency.

TABLE 9

Underway Measurements of Maximum Vibratory Displacements of Hull, Island, Radar Mast, Main Propulsion Machinery, and Mark 63 Director 2 during Crashback

Gage Location	Vertical Vibration		Athwartship Vibration		Longitudinal Vibration	
	Frequency of Vibration cps	Single Amplitude mils	Frequency of Vibration cps	Single Amplitude mils	Frequency of Vibration cps	Single Amplitude mils
Hull, Stern Frame 135	4.7	30.1	4.8	21.7	-	-
Island 03 level	4.8	12.3	4.9	11.9	-	-
Island 07 level	4.8	12.5	10.8	19.8	4.8	8.0
Radar Mast 30 ft above 07 level	-	-	10.8	25.5	4.8	15.1
Radar Mast 58 ft above 07 level	-	-	10.8	32.0	4.8	70.6
Thrust-Bearing Foundation	-	-	-	-	9.8	12.5
Thrust Bearing	-	-	-	-	9.8	7.6
Condenser	-	-	-	-	9.8	15.0
Flexible Coupling	-	-	-	-	9.8	26.1
Director Base, Frame 63	4.8	24.7	4.8	31.0	4.8	5.4
Director Top Pedestal, Frame 63	4.8	21.0	4.8	34.9	9.1	9.8
Director Eyepiece, Frame 63	4.8	33.5	9.1	145.8	9.1	37.0

TABLE 10

Magnification Factors of the Island-Radar Mast Structure during Ship Maneuvers

Gage	Location	Direction	Magnification as Compared to Island		
			Crashback	Port Turn	Starboard Turn
A2	Radar Mast 58 ft above 07 level	Athwartship Longitudinal	2.7 2.6	5.9 10.7	6 11.3
A1	Radar Mast 30 ft above 07 level	Athwartship Longitudinal	2.1 1.9	5.3 2.1	5.1 4.5
S2	Island 07 level	Athwartship Longitudinal	1.6 1	4.8 1	5.0 1
S1	Island 03 level	Athwartship	1	1	1

5.8 cps; higher modes were uncertain. Ratios of the higher vertical hull modes to the fundamental vertical mode follow the series 1, 1.6, 2.2, 2.8, etc., as contrasted with the series 1, 2, 3, etc. found on a number of surface ships.[5] A possible explanation for the latter result may be found in the superstructure geometry of OKINAWA, which is characterized by a lack of shear continuity over the length of the hull above the hanger deck.

Athwartship vibration amplitudes at the top of the island had large amplification relative to the base of the island at speeds above 85 rpm, indicating that the island behaves as a cantilevered beam at high ship speeds. The measured data further indicated that the large athwartship island motions involved the entire island-radar mast structure. On the basis of vibration computations of this structure made by the Bureau of Ships, it was recommended that the topmast on all LPH-2 class ships be stiffened by increasing the inertia at its base and top and simultaneously reducing the plating thickness in order to approximate the weight of the original topmast.

The measured amplitude profile of the blade frequency component of mast athwartship vibration at 115 rpm (Figure 16) shows that large motions occurred in the vicinity of the topmast; in particular, there was relatively large rotation at a nodal point along the topmast. Although the recommended redesign of the topmast would be expected to mitigate the vibration of the upper mast, it would not be expected to significantly change the motion of the entire island-radar mast structure; no vibration measurements on the redesigned mast structure have been made, however, to substantiate this.

It should be noted that up to the main or hanger deck of OKINAWA, the midship depth of the hull is 47.2 ft whereas the depth to the flight deck is 76.8 ft. As noted from the midship hull cross section (see Figure 22), the plating thickness of the superstructure from the main deck to the flight deck is able to sustain substantial bending and shear loads. Consequently, empirical equations for estimating the fundamental vertical mode of ships with superstructures like those of the LPH-2 class should include the inertia of the superstructure from the main deck to flight deck in addition to the hull inertia and/or should consider the effective depth to be greater than the depth to the main deck. It cannot be concluded with certainty whether the depth up to the flight deck should be used to yield a more accurate prediction of the fundamental vertical frequency from empirical equations (some percentage of this depth would probably be more realistic). It is, however, important that some allowance be made for the dynamic influence of the superstructures on the hull vibrations for ships with superstructure geometry similar to the LPH-2 class.

Although the estimated hull damping values for OKINAWA lie within the range of expected values,[5] the coefficients vary considerably for the first four vertical modes. Further effort is required in all aspects of ship damping before discrepancies between computed and measured hull response can be minimized. Such effort should include methods of exciting hull vibrations, methods of determining damping from experimental data, and methods of applying damping in computation.

TABLE 11

Estimates of Hull Damping Coefficients $c/\mu\omega$ for Vertical Vibration of OKINAWA from Analyses of Anchor Drop Data

Mode	Frequency cps	Manual-Analysis of Oscillograms		Electronic-Graphical Analysis of Tape Records	
		Number of Decay Cycles Analyzed*	$c/\mu\omega$	Number of Decay Cycles Analyzed	$c/\mu\omega$
First	1.9	40	0.005	12	0.007
Second	3.1	14	0.012	12	0.008
Third	4.2	-	-	9	0.029
Fourth	5.4	-	-	8	0.020

*This value refers to the number of cycles for which the decay amplitudes were approximately linear when plotted on a semilogarithmic graph; $c/\mu\omega = \delta/\pi$ (see Reference 5).

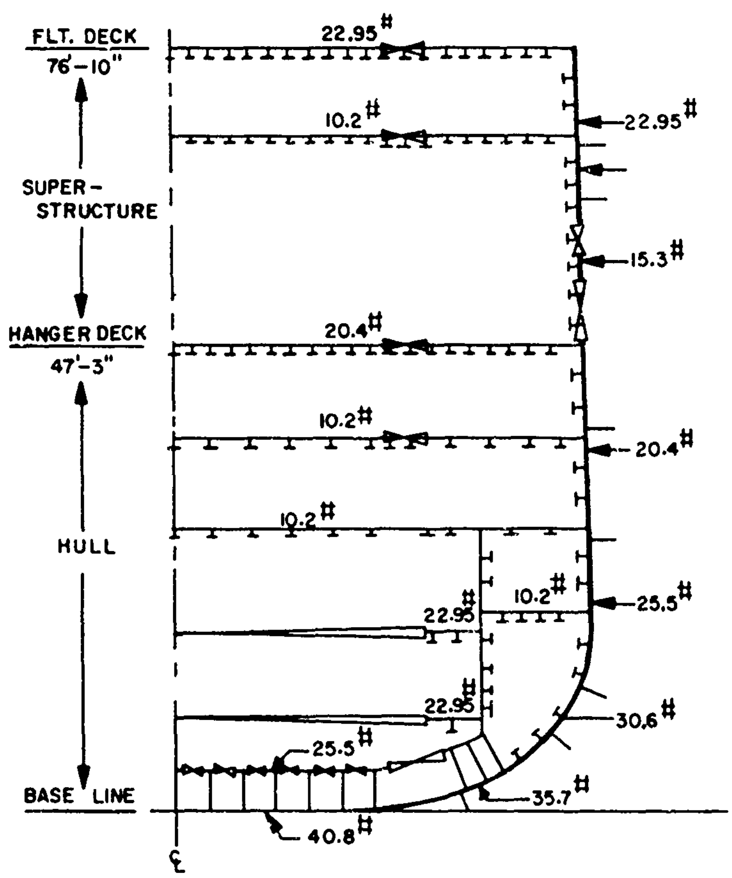


Figure 22 – Hull Cross Section of OKINAWA at Midship Showing Plating Thicknesses in Hull and Superstructure up to the Flight Deck

CONCLUSIONS AND RECOMMENDATIONS

It is apparent from the analysis of vibration data on OKINAWA that superstructures of the type found on the LPH-2 class can affect the vibratory response of the ship in two respects which are of interest to the designer. Foremost is the possibility that large vibrations of island-mast structures can be induced by propeller-excited forces. This may be particularly true (1) if the island-radar mast structure offers little resistance to motion in a particular direction and/or (2) if the attachment of the island-radar mast to the superstructure in the vicinity of the island is not sufficiently stiff. This problem assumes particular importance for sensitive electronic equipment mounted on the radar mast and island; if there is excessive vibration of these structures, the equipment may not operate acceptably.

The second important effect of the superstructure on LPH-2 class ships is its influence on the vibratory response of the main hull girder. For aircraft carriers, the hangar deck is usually the main strength deck. There are transverse bulkheads which extend from the main deck to the flight deck at the extremities of the hull but do not span the length of the hangar deck. Thus, the superstructure of OKINAWA contributes to the shear stiffness of the main hull girder but is relatively less stiff over the length of the hangar deck. The practical importance of this is that the naval architect cannot use the empirical ratios of 1, 2, 3, etc. for estimating the ratios of the higher flexural hull frequencies to the fundamental frequency with confidence for ships having superstructures similar to that of the LPH-2 class.

The conclusions from the analysis of vibration data on the propulsion system are:

1. None of the amplitudes measured on the propulsion machinery is considered excessive.

2. The rapidly increasing amplitudes at propeller blade frequencies in the high power range are attributed to the close proximity of the frequency of the propeller-exciting forces to the fundamental natural frequency of the propulsion system (see Appendix A).

3. The longitudinal natural frequency of the propulsion system is about 110 percent of full power rpm, resulting in the rapid amplitude buildup in the high power range. (Specifications for longitudinal vibration of propulsion systems (Reference 8) state that the propulsion system must be free of any longitudinal critical frequency between 50 to 115 percent of full power rpm.) The important practical result found from vibration analysis of the main propulsion system was that replacement of the four-bladed propeller with either a five-bladed or three-bladed propeller could not be expected to solve the problem of excessive island-radar mast vibration on OKINAWA.

As a result of the measurement and analysis of vibrations on OKINAWA, the following recommendations are made:

1. Mast vibrations should be analyzed on various class ships in order to determine what types of construction are most effective in limiting environmental vibration of electronic equipment mounted on the masts and superstructure in the vicinity of masts.

2. Experimental investigations should be supplemented by analytic investigations of coupled hull-superstructure-radar mast vibrations as, for example, on an electric analog computer.

3. For future vibration surveys, measurements should be made in the vicinity where masts are connected to the superstructure in order to obtain improved information on the physical boundary conditions for dynamic analyses.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of Mr. A. Zaloumis in the preparation of the material on vibration measurements and analysis of the propulsion system. Thanks are also due to Mr. E. Noonan, Dr. E. Buchmann, and Mr. S. Lee for their constructive criticism and suggestions and to Mr. V. Hardy, Mr. R. Tuckerman, and Mr. B. Vorhauer for their assistance in the preparation and interpretation of the data.

APPENDIX A

SHAFT VIBRATION CALCULATIONS

Calculations of longitudinal shaft vibrations including the influence of the propeller and machinery components were performed on an electric analog computer to help interpret the measured results. The mechanical system assumed for the longitudinal shaft vibration calculations is shown in Figure 23. It consists of six discrete masses and springs connected in series representing the propeller-shaft-machinery system. Figure 23 also shows the calculated mode shapes for the first three natural frequencies which were found to be 8.9, 22.1, and 37.3 cps, respectively.

An examination of longitudinal machinery vibrations shown in Figures 20 and 21 indicate that a resonant condition of the propulsion system is being approached at maximum shaft rpm. The second-order blade frequency forces excite three distinct resonances of the main propulsion machinery. The calculated fundamental frequency for the propulsion system of 8.9 cps agrees well with the measured peak at 8.7 cps. The measured resonances at 10.7 and 13.3 cps and the relative phase of the machinery components measured at these frequencies indicate that the propulsion system is more complex than the model assumed for the calculation. This was not investigated in further detail since the vibration levels of the machinery components were not excessive and determining the structural characteristics of the machinery components for a more realistic mathematical model would have required more extensive analysis.

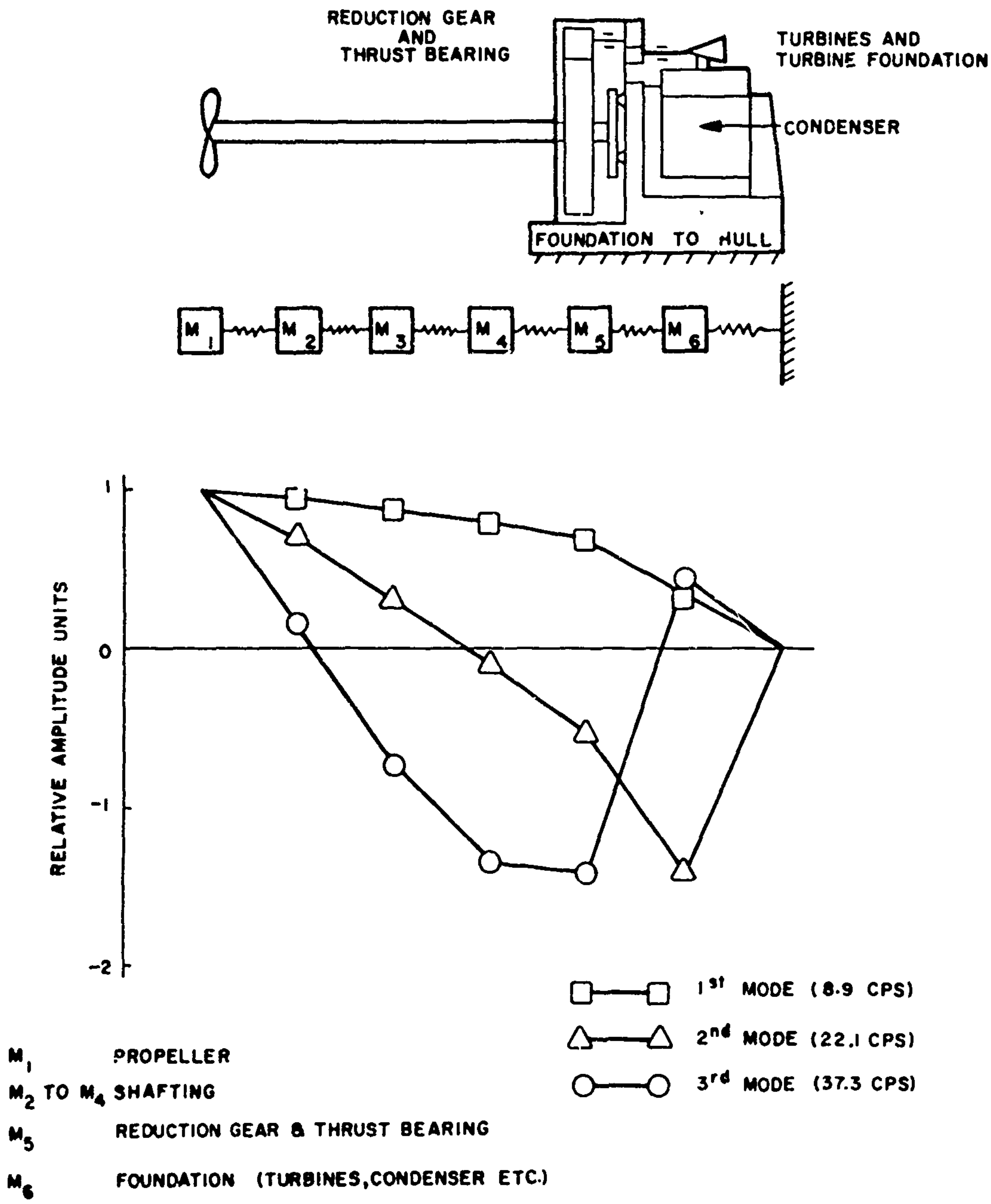


Figure 23 – Mechanical Model and Relative Mode Shapes for Longitudinal Vibrations of OKINAWA Propulsion System

APPENDIX B

ELECTRONIC ANALYSIS OF ANCHOR DROP TAPE RECORDS

Estimates of hull damping and modes are increasingly difficult to obtain from oscillogram records for modes above the fundamental hull frequency because of (1) the superposition of many frequencies with decaying amplitudes at relatively low frequencies and (2) the short length of the records. Thus an "electronic-graphical" analysis was employed to supplement the information obtained by the manual analysis. This procedure employed tunable narrow band-pass filtering of the tape records in order to obtain decay signals of the frequency components corresponding to the first four hull modes of vertical vibration.

To obtain an estimate of hull damping from magnetic tape records of the anchor drop test, an electronic filtering technique introduced by Mazet[7] and employed by Kilcullen[8] for ship vibrations was used. This procedure calls for rerecording the transient signal onto a continuous magnetic tape loop and playing this signal in reverse time sense into a narrow band-pass filter to avoid shocking the filter. The resonant frequencies contained in the signal were found by sweeping the frequency of the filter and making a spectrum plot as shown in Figures 24 and 25. For each frequency of interest, a filtered record was obtained in which the center frequency of the filter was fixed.

The amplitudes of vibration were plotted on a logarithmic scale versus a linear scale representing the cycle number for each frequency component of the recorded signal. The purpose of this step was to determine the approximately exponential portion of the transient signal (i.e., the linear portion of the semilogarithmic plot) since only this portion is representative of linear damping which is assumed in hull forced response calculations.[5] T' damping coefficient $c/\mu\omega$ used in these calculations may be obtained from the logarithmic decrements corresponding to the linear portion of the semilogarithmic plot since $c/\mu\omega \approx \delta/\pi$ for small damping.[5] The results are tabulated in Table 11.

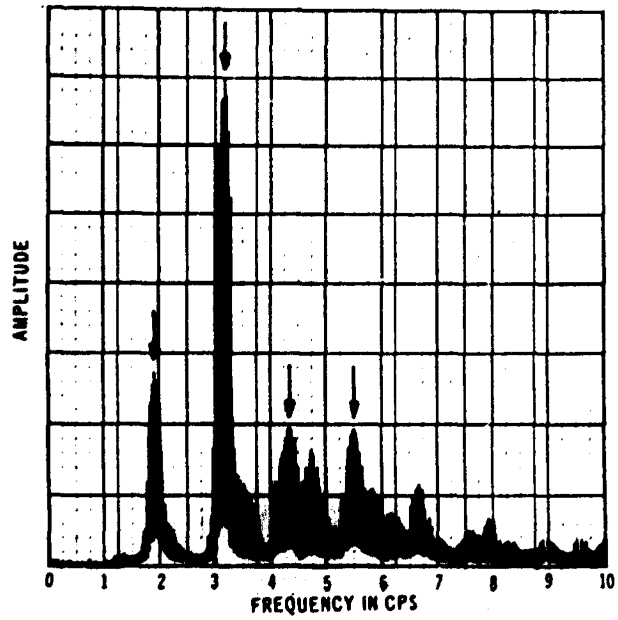


Figure 24 – Amplitude-Frequency Spectrum of Hull Vertical Vibration of OKINAWA Recorded by Gage H8V (Frame 13, Main Deck Centerline) during Anchor Drop Test

Arrows indicate hull vertical natural frequencies.

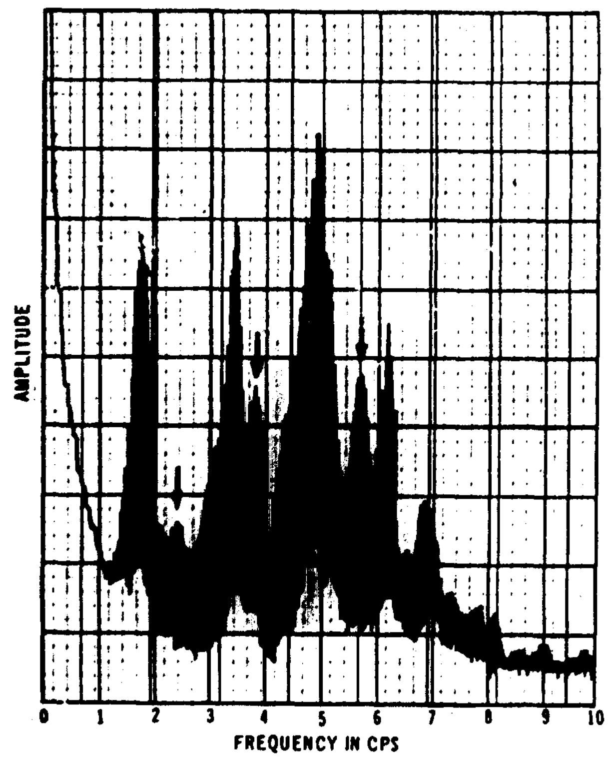


Figure 25 – Amplitude-Frequency Spectrum of Hull Athwartship Vibration of OKINAWA Recorded by Gage H9A (Frame 13, Main Deck Centerline) during Anchor Drop Test

Arrows indicate hull athwartship natural frequencies.

APPENDIX C

VIBRATION DATA SHEET

In order to summarize the principal results found during the underway vibration tests on OKINAWA, a summary data sheet is given as Figure 26. Included in this sheet are the vessel characteristics, test conditions, and test equipment.

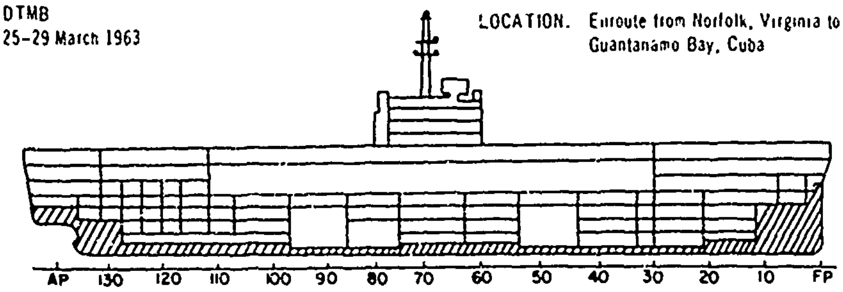
The graphs in the chart summarize the vertical and athwartship maximum vibration levels found at the stern (main deck centerline, Frame 135) and the athwartship and longitudinal maximum vibration levels at two mast positions. The table also summarizes the maximum vibration levels of (1) the hull at the bow (Frame 13) and at midships (Frame 67), (2) two positions on the island, and (3) the thrust bearing and thrust-bearing foundations. It should be noted that the maximum levels of first-order vibration shown in the graphs were estimated from average amplitudes, determined by electronic analysis of tape records, since first-order amplitudes could not be easily obtained by visual analysis of oscillogram records. Maximum first-order levels were estimated by multiplying the maximum fourth order amplitudes by the ratio of the average amplitudes of first- to fourth-order components.

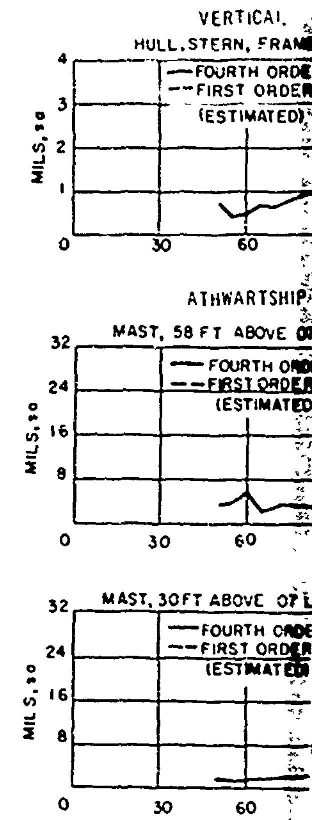
CLASS LPH-2

TEST. ACTIVITY DTMB
DATE 25–29 March 1963

SHIP USS OKINAWA (LPH-3)

LOCATION. Enroute from Norfolk, Virginia to Guantanamo Bay, Cuba





VESSEL CHARACTERISTICS

Light Displacement	15,691 tons	Length Overall	602 ft 3 1 2 in.
Test Displacement	17,700 tons	Length between Perpendicular	556 ft 0 in.
Mean Draft (test)	25 ft 10 1 2 in.	Beam	84 ft 2 1 8 in.
Trim by Stern (test)	3 ft 9 in.	Depth	47 ft 2 in.

Type of Propulsion Machinery: cross-compound two-casing turbine, double reduction gear.

Propellers

Type Magnesium Bronze
No. of Propellers 1
Propeller Blade Tip Clearance 5 ft 6 in.
Number of Blades 4

TEST CONDITIONS

Maximum Speed in Knots
Maximum RPM 118
Test Speed Range 50–118 RPM
Sea State: 3–4 Swell

Minimum Water Depth during test over 500 ft

TEST EQUIPMENT: CEC Type 4-102A velocity pickups CEC System D Type 1-112C linear integrating amplifiers, CEC Type 5-119 36-channel string oscillograph CEC Type PR-2300 and PR-3300 14-channel tape recorders.

SUMMARY OF VIBRATION DATA

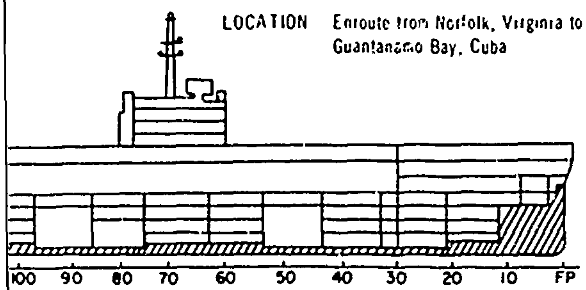
Location of Measurement	Direction	Shaft RPM	Order	Frequency CPM	Mils sa	Remarks
Hull, Bow, Frame 13	Vertical	50	Fourth	3.3	0.5	-
Hull, Bow, Frame 13	Athwartship	75	-	5.0	1.9	-
Hull, Main Deck, Frame 67, Port	Vertical	118	-	7.9	0.5	Near sixth hull vertical mode.
Hull, Main Deck, Frame 67, Starboard	Vertical	118	-	7.9	0.9	Near sixth hull vertical mode
Hull, Main Deck Frame 67, Centerline	Athwartship	75	-	5.0	1.0	
Hull, Stern, Frame 135	Vertical	118	-	7.9	2.4	Near sixth hull vertical mode.
Hull, Stern, Frame 135	Athwartship	115	-	7.6	3.[illegible]	Fourth hull athwartship mode
Island 03 Level	Vertical	110	-	7.3	7.0	Near sixth hull vertical mode.
Island 03 Level	Athwartship	118	-	7.9	4.0	Near fourth hull athwartship mode.
Island 07 Level	Vertical	118	-	7.9	2.6	Near sixth hull vertical mode
Island 07 Level	Athwartship	118	-	7.9	17.8	Near fourth hull athwartship mode.
Island 07 Level	Longitudinal	115	-	7.6	3.0	Near sixth hull vertical mode.
Mast, 30 Ft Above 07 Level	Athwartship	118	-	7.9	28.8	Near fourth hull athwartship mode
Mast 30 Ft Above 07 Level	Longitudinal	115	-	7.6	9.0	Near sixth hull vertical mode
Mast 58 Ft Above 07 Level	Athwartship	115	-	7.6	31.2	Fourth hull athwartship mode.
Mast 58 Ft Above 07 Level	Longitudinal	118		7.9	13.7	Near sixth hull vertical mode.
Thrust Bearing	Longitudinal	118	-	7.9	9.0	Below fundamental shafting mode.
Thrust Bearing Foundation	Longitudinal	118	-	7.9	5.4	Below fundamental shafting mode.

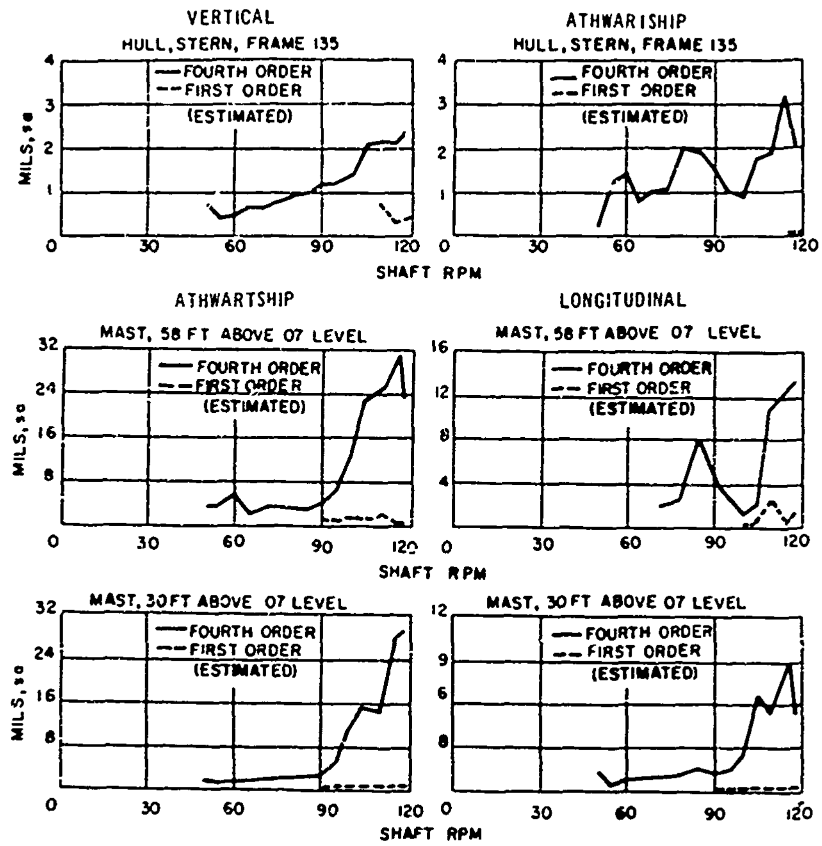
Figure 26 – Vibration Data Sheet for OKINAWA

B

SHIP USS OKINAWA (LPH-3)

LOCATION Enroute from Norfolk, Virginia to Guantanamo Bay, Cuba





l 602 ft 3 1 2 in.
n Perpendicular 556 ft 0 in.
84 ft 2 1 8 in.
47 ft 2 in.

g

h
ft

C System D Type 1-112C linear
illograph, CEC Type PR-2300

RATION DATA

Frequency CPM	Mils sa	Remarks
3.3	0.5	-
5.0	1.9	-
7.9	0.9	Near sixth hull vertical mode.
7.9	0.9	Near sixth hull vertical mode.
5.0	1.0	
7.9	2.4	Near sixth hull vertical mode.
7 6	3.2	Fourth hull athwartship mode.
7.3	2.0	Near sixth hull vertical mode.
7.9	4.0	Near fourth hull athwartship mode.
7.9	2.6	Near sixth hull vertical mode.
7 9	17.8	Near fourth hull athwartship mode.
7 6	3.0	Near sixth hull vertical mode.
7.9	28.8	Near fourth hull athwartship mode.
7 6	9.0	Near sixth hull vertical mode.
7 6	31 2	Fourth hull athwartship mode.
7 9	13 7	Near sixth hull vertical mode.
7 9	9 0	Below fundamental shafting mode.
7 9	5 4	Below fundamental shafting mode.

Figure 26 – Vibration Data Sheet for OKINAWA

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13 ABSTRACT

An underway vibration survey was performed on USS OKINAWA (LPH-3) to establish critical frequencies and determine maximum vibratory levels of the hull, island, radar mast, main propulsion machinery, and Mark 63 Director 2. Free route (straight course) steady-speed runs were made in addition to hard turns, crashback maneuvers, and anchor drop tests. Large magnifications of athwartship vibration motion of the island-radar mast structure relative to the hull were noted for speeds above 85 rpm. The superstructure of OKINAWA influences the island and radar mast vibrations whose levels are important for the successful operation of electronic equipment mounted on these structures. Because of the characteristics of the superstructure, the ratio of the higher flexural hull frequencies to the fundamental frequency differs from that found on a number of other class vessels.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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